NEWFOUNDLAND

DEPARTMENT OF NATURAL RESOURCES

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GEOLOGICAL SECTION

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BULLETIN No. 9

GEOLOGY AND MINERAL DEPOSITS OF THE HARE BAY AREA

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GOLDEN, COLORADO

ST. JOHN'S
1937

PREFACE

This bulletin is based on field work done during the summer of 1936 on the general and economic geology of Hare Bay.

The author was assisted in the geological phases of the work by Kirk Stephenson, a senior student in the Department of Geology at Mount Union College, Alliance, Ohio. The Department of Natural Resources has coöperated through various members of its staff: William J. Nugent conducted transit-and-stadia surveys of Ireland Brook and Bartletts Brook, J. F. Newman of the Government Laboratory made the assays which are incorporated in the report, and the final draughting of the geological map was done by W. B. Titford of the Department of Natural Resources, St. John's, Newfoundland. The bulletin was written and much of the laboratory work was done at Mount Union College. A microscopic study of polished sections of the ores collected was made by Dr. R. P. Fischer in the geological laboratory of Princeton University.

It is a pleasure to express grateful acknowledgment and hearty thanks to those who have helped in carrying out the work. The author cannot over-emphasize the fine coöperation of the Government Geologist who has given assistance and advice at every stage of the work. The identification of fossils by Professor Carl O. Dunbar of Yale University and the metallographic study by Dr. R. P. Fischer have been of great assistance. Miss Joyce Wingerd has done much careful work in preparing the manuscript.

The author is particularly indebted to his assistant, Mr. Stephenson, for making a detailed study of the Goose Cove copper deposits, the results of which are incorporated in this bulletin. While acknowledging fully this assistance, the author assumes responsibility for the opinions expressed.

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INTRODUCTION

LOCATION AND AREA

The Hare Bay map area lies near the extremity of the Northern Peninsula of Newfoundland; its location is shown on the index map of Plate I (in pocket). The area embraces the land surrounding Hare Bay and a belt of country extending northeastward to the southern part of Pistolet Bay. The total area is 750 square miles, approximately half of which is covered by bays and inlets.

Although most of the area is uninhabited, there are numerous fishing villages along the shore. The largest of these is St. Anthony which is the chief port of northern Newfoundland and the home of the mission of the International Grenfell Association. St. Anthony and several other settlements in the map area are served by the Newfoundland Railway Steamships running from St. John's to Labrador and to Humbermouth, west coast of Newfoundland. During the summer months, Clarke Steamship Company, Ltd. operates between Montreal, Quebec, and St. Anthony. The steamship services make the region readily accessible most of the year. The bays are frozen during the winter months. The area is then isolated except for telegraph and mail service, mail being transported 160 miles by dog team to the nearest point on the Newfoundland Railway.

GEOLOGICAL SETTING

The Hare Bay map area lies at the northern end of the exposed Appalachian mountain system but there is no indication that the deformed belt dies out. Folded and thrust-faulted rocks of Ordovician and possibly younger age strike northeastward beneath the Atlantic Ocean. The western boundary of the area is only 25 miles southeast of the pre-Cambrian crystalline rocks of the Labrador part of the Canadian Shield. Nearly horizontal lower Cambrian strata lap over the Canadian Shield along the Labrador coast, and across the narrow Strait of Belle Isle generally flat-lying lower Ordovician rocks form the west coast of Newfoundland. This is part of the undeformed foreland of the Appalachian mountain system.

The Paleozoic sedimentary succession of western Newfoundland is very different from that of Notre Dame Bay on the northeast coast although faunal evidence indicates that both were deposited in the St. Lawrence geosyncline (10, 17).* The Long Range Mountains, a geanticlinal axis of pre-Cambrian rocks, at present separates the two regions. The axis of this uplift runs parallel to the west coast and about twenty miles inland. Its continuation lies southwest of Hare Bay. The Long Range axis came into being as early as middle Ordovician time as shown by the Cow Head breccia of western Newfoundland (17) and Heyl has suggested that it may have been a land barrier even earlier in the Ordovician (10, pp.12-13). If such a land barrier existed, it must have run east rather than west of the Hare Bay area since in both lithology and fauna the Hare Bay rocks are similar to those of the west coast.

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*Numbers refer to bibliography, p. 34.

PHYSIOGRAPHY AND GLACIAL GEOLOGY

TOPOGRAPHY

All except the western margin of the area is formed by hills ranging from several hundred to 1,012 feet in altitude. As is the case with land surfaces resulting from ordinary erosion processes, the more resistant rocks form the hills and uplands, whereas the less resistant rocks have been eroded and underlie valleys and lowlands. In general, the bedrock of the region is resistant and the land is an upland in a moderate stage of dissection. The hills rise abruptly from the sea, commonly as cliffs a hundred or more feet high where the shore is exposed to storm waves from the Atlantic. This feature, together with the general absence of trees from the hilltops, gives most of the region a bleak, desolate aspect (Fig. 1).

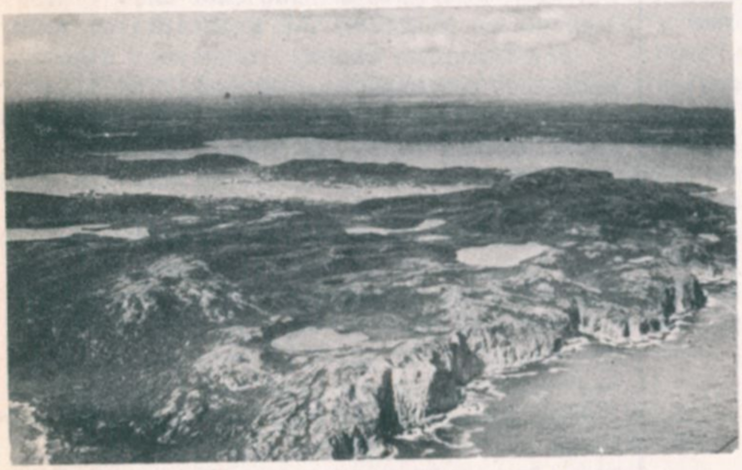

Fig. 1. Aerial photograph of the eastern part of the region; St. Anthony Harbour in the middle distance. (Photograph by A. K. Snelgrove.)

Peridotite which is very resistant to erosion underlies the highest land. Two large masses between Hare Bay and Pistolet Bay form the White Hills, and the mass west of Howe Harbour forms the similar but smaller Sea Mountain, known locally as the Deer Barren. The White Hills, which are separated into an eastern and western hill by the valley of Ireland Brook, are the central topographic feature of the region. They are little dissected, rocky uplands averaging approximately 600 feet in altitude. The summits are rolling, treeless surfaces of moderate relief surmounted by conical peaks, several of which slightly exceed 1,000 feet above the sea. The gneisses which form a contact aureole around the peridotite intrusions are only slightly less resistant than the peridotite itself and form prominent hills surrounding the peridotite areas. They are wooded or scrub-covered and are separated topographically from the White Hills by a U-shaped valley which coincides with the contact of gneiss with peridotite and owes its origin to a more easily eroded border phase of the peridotite. Tangential streams and ponds occupy the marginal valley in most places. Few of these have been mapped but they are well exemplified by the long ponds at the head of Bartletts Brook (Plate I).

East of the White Hills and the aureole of gneissic hills, Goose Cove schist and a sandstone form barren or scrubby hills which are considerably lower. The sandstone hills are for the most part less than 300 feet in altitude and the schist hills seldom exceed 400 feet. West of the White Hills the land is much lower. A remarkably flat and extensive bog stretches between North Arm of Hare Bay and Pistolet Bay, bounding the map area on the northwest. The southwestern part of the map area, which is underlain by slate and limestone, is low, rolling country without prominent topographical features. Some of the limestone hills exceed 200 feet in height, but for the most part it is rolling, wooded country less than 100 feet in elevation.

The rolling uplands which are present in many parts of the region, and which truncate tilted and folded beds, are the result of erosion. That they were cut by stream erosion rather than by marine denudation is indicated by conical residuals upon them. Whether only one or several previous cycles of erosion are indicated must await more detailed study. No single perfect upland peneplain is evident and until more positive data is secured, it is best to consider that the land once stood a few hundred feet lower than now and was reduced to a rolling land surface of considerable relief but subdued topography.

DRAINAGE

A number of large brooks are found in the Hare Bay region but only one of these may properly be called a river. This is Salmon River (known locally as Main Brook) which rises on the Long Range axis far to the west and flows into Southern Arm of Hare Bay. According to local report, it is large enough to be travelled by canoe to near its head from whence but a short distance intervenes to the headwaters of some of the large brooks flowing into the Gulf of St. Lawrence. It thus provides one of the most convenient routes across the Northern Peninsula of Newfoundland for the purposes of geological study.

The present erosion cycle was initiated by Pleistocene glaciation and concomitant isostatic adjustments. It started so recently that subsequent streams are rare and as yet poorly developed. Nearly all the streams are in the extreme youthful stage of development, with falls, rapids, lakes, and ponds along their course. Where they are adjusted to belts of soft rock and flow in open valleys, as does Ireland Brook, the valleys are a more or less ice-modified inheritance from a preglacial land surface on which the streams were adjusted to rock structure.

Lakes, ponds, and marshes are numerous and occur at almost all levels from near sea-level to the hilltops. Many of the larger, more prominent ponds occupy depressions scoured out by glacial ice or formed by the damming of valleys by glacial debris. The rest are shallow marsh ponds. Although small for the most part, they are present in such numbers as to cover half the surface in some places. The marshes themselves are of the type known as muskeg in Canada.

SHORE LINE AND SEA FLOOR

Although there are indications that the whole of northern Newfoundland is emerging, the coastal features show most clearly the effects of a greater previous submergence. The Hare Bay region has a shore line of submergence in the youthful stage of development. Submergence is shown by a very irregular shore which gives rise to numerous bays and coves, and by more than forty small islands. Sea cliffs bordered by deep water, and a general restriction of beaches to bays and coves, indicate a youthful stage in the cycle of shore line development.

On the whole, glacial erosion has been of slight importance in determining the shore line or the sea floor. The maximum sounding in Hare Bay is 48 fathoms, and in Pistolet Bay, only 16 fathoms. The bays are shallower than the sea immediately off shore, and in profile suggest stream-cut valleys. Only the troughs trending northwest-southeast, such as St. Mein Bay (maximum depth 45 fathoms), appear to have been broadened and deepened by glacial scour. The absence of fiords like the Bay of Islands (5) and of fiards like the Bay of Exploits (10) indicates that the local Wisconsin glaciation which affected central Newfoundland so intensely was of slight importance farther north. The only positive local evidence of a northern Newfoundland ice-cap are northeast-trending striae observed at three places in Southern Arm of Hare Bay.

A recent emergence of the land is shown by raised beaches and wave-cut benches. The highest of these is a terrace 250 feet above sea-level which is perfectly preserved on the peridotite mountain slopes around Howe Harbour. It is a wave-cut bench for it cuts horizontally across tilted peridotite bands and is bordered on the landward side by a high, steep cliff. In places, its surface is a quarter of a mile wide and is mantled by gravel. The size and perfection of the terrace indicates that the sea stood at this level for a considerable time. Another bench, estimated at 30 feet above sea-level, is present at a number of places in the region.

The terraces are correlated with the post-glacial terraces of Labrador and other parts of Newfoundland, and appear to record the isostatic rebound of the earth's crust after having been depressed by the great weight of glacial ice. The occurrence of waterfalls along the coast may indicate that the uplift is still progressing.

GLACIAL GEOLOGY

The Hare Bay area contains abundant evidence of glaciation in the form of rock-basin lakes, erratics, and planed-off rock surfaces which in places are grooved and striated. That the entire area was covered by ice is shown by the presence of erratics on the highest summits. Most of these are locally derived, but among them were found boulders of anorthosite, gneiss, and other rocks which have been carried into the region from elsewhere, possibly from Labrador. Southeastward ice movement is shown by striae at St. Anthony and Cape Bauld and is suggested by broad U-shaped troughs like that of Ireland Brook which have a south-southeast to southeast trend. It is concluded that the effective glacial erosion was accomplished by ice which moved across the Strait of Belle Isle from the Labrador center. The freshness of some of the erratics suggests Wisconsin glaciation but it may be chiefly Jerseyan, the Hare Bay region having been largely free from Wisconsin ice. Such a lack of Wisconsin glaciation in large parts of northern Newfoundland is postulated by Fernald (9, 3) on the basis of botanical evidence. According to his views, the occurrence of localized, endemic plant species of Cordilleran aspect, along with numerous other species unknown outside of western America, Alaska, and Siberia, is best explained by assuming that the species lived through the Wisconsin stage on local ice-free areas.

STRATIGRAPHY

STRATIGRAPHIC COLUMN

A varied stratigraphic succession aggregating over 13,000 feet in thickness is displayed in the Hare Bay area. No single complete section is exposed, but large parts of it are revealed in places, the most complete section being along the south shore of Hare Bay. The succession given in Table I is based primarily on this section but is supplemented by information secured elsewhere. It is therefore a composite section for the whole area. The formations have been delimited on the basis of lithology and available faunal evidence. Owing to structural complexities, the thicknesses are necessarily approximations.

The whole series is divisible into three parts on the basis of lithology: (1) A lower division consisting of limestone (formations 1, 2, 3 of Table I); (2) A middle division characterized by shale with thin beds of more or less sandy limestone (formations 4 and 5); and (3) An upper division characterized by coarse, somewhat pebbly sandstone which grades locally into conglomerate (formations 6 and 7). Lava flows, tuffs, and pyroclastic breccias are abundant in the upper part of the succession. They first appear near the top of division (2), and at the top of division (3), they are preponderant over the sedimentary rock. Fossils were found only in division (1) and these indicate the age as Ordovician; Dunbar, who examined

Table I

ORDOVICIAN OF NEWFOUNDLAND

General Time Scale		Southeastern Newfoundland	Notre Dame Bay	Western Newfoundland	Hare Bay
Ordovician	Black River and Trenton		Undefined group of sandstones, shales and shaly limestone	Humber Arm Series 5,000'+	7. Ireland Point Volcanics--2,000' 6. Maiden Point Sandstone--6,000' 5. Goose Tickle Slate 2,000'-5,000'
				Cow Head Breccia Long Point Series 1,530'	? 4. Northwest Arm Formation 0-500'
	Chazy	Gravel Head Formation (?)	Exploits Series 12,000'+	Table Head Series--1,380'	? 3. Hare Island Limestone--1,000'
	Canadian	Wabana Series Bell Island Series Clarenville Series	Snooks Arm Series	St. George Series 1,570'-2,080' Green Point Series 1,700'+	2. Southern Arm Limestone--1,500'± 1. Brent Island Limestone--350'+

them, believes that all occur in the west coast faunas, the majority from the Table Head limestone (Chazy), but some from the St. George series (Canadian). It is likely that the whole series is Ordovician although the lowermost 350 feet (Brent Island formation) may be Cambrian, and the whole of divisions (2) and (3) may be post-Ordovician. In its general features, the whole succession resembles that of the west coast of Newfoundland with which it is compared in Table I.

DESCRIPTION OF FORMATIONS

Brent Island Limestone

The sole outcrops of this formation are in the southern part of North Brent and South Brent Islands. A good section is exposed along the southern shore which crosses the strike of the gently dipping beds at a small angle. The thickness of beds exposed is estimated at 350 feet. The formation consists of well-bedded, dark grey limestone with slaty horizons and numerous chert nodules. The limestone, which is in beds several feet or less in thickness, is in part hackly and in part laminated. For the most part of a dark blue-grey color, it contains some beds of pale-weathering stone a few feet thick. Some of the dark limestone is slaty, and slates are present, but not exposed, in several coves along the shore. The chert varies from very pale grey to black and in some places weathers flesh color. It is abundant, occurring as nodules and lenticular masses parallel to the bedding.

A few fossils are present, but they are poorly preserved and the age of the formation cannot be established on faunal evidence at the present time. The structural relations suggest it is part of the St. George series (Canadian), but it differs from the described sections of that series in the presence of chert. Lithologically, it is similar to the top of the "Potsdam group" of Canada Bay as described by Murray many years ago (13, pp. 4-47). Describing the top 660 feet of this series, he wrote, "Blue and dark-grey, massive limestone, interstratified with brown slates in equal quantities. The limestone, at the summit, holds numerous nodules of black chert weathering yellowish, which is arranged in layers parallel with the stratification." It is hoped that geological work now being carried on by the Geological Section will establish the relationship of these strata to the better-known succession of the west coast.

Southern Arm Limestone

No continuous section of this formation is exposed in the Hare Bay area. Its name is taken from Southern Arm of Hare Bay where the best outcrops and most complete though partial sections are exposed. Estimates of thickness are uncertain owing to minor folds and the necessity of estimating over unexposed areas. It is certainly more than 500 feet, and may be as great as 2,000 feet thick. Fifteen hundred feet is a probable figure.

The base, exposed on North Brent Island, is in sharp contact with the Brent Island limestone and may be a disconformity. The top was not observed, the contact being drawn on lithologic grounds in accord with faunal evidence. Where the contact crosses Maria Island, vertical dyke-like bodies of sandy limestone cut what is taken to be Southern Arm limestone which here dips 30 degrees toward the southeast. It is thought that these are fissure-fillings, which are a common feature in limestones beneath unconformities. It suggests that a disconformity separates the Southern Arm and Hare Island limestones in the same fashion as a disconformity separates their correlatives of the west coast (St. George series and Table Head series).

In 1864, Murray described the rocks of the southwestern part of Hare Bay, then called Belvie Bay (13, pp. 20-47). Although his section is correct in its general features, it is so faulty in detail that it is undesirable to repeat it here. The Southern Arm limestone, embracing Murray's units 1, 2, and part or all of 3, consists dominantly of hard, light grey limestone which is more or less hackly. In some places it is quite massive but in others it is well bedded, locally even thin bedded.

Fossils are present at many places but most of them are not well preserved. A collection was sent to Professor Dunbar of Yale University who reports that they are from the St. George series. The fossils include high- and low-spired gastropods, cephalopods, and a sponge. *Euchasma* blumenbachi and Maclurites affinis were identified by him among fossils secured in the lower part of the formation on North Brent Island. A cephalopod which may be Protocyloceras lamarcki is associated with small Maclurites, probably M. affinis, near the top of the formation in Northwest Arm. Murray recorded the following from his division 2 in the southwest part of the bay: Murchisonia simulatrix, Maclurea Normani, Piloceras Wortheni, Orthoceras Allumettense, and Bathyurus Nero. These fossils indicate that the formation is part of the St. George series as developed along the northwest coast of Newfoundland and is of lower Ordovician (Canadian) age.

Hare Island Limestone

This formation, named for its characteristic exposures on Hare Island, lies with probable disconformity above the Southern Arm limestone. Estimates of thickness in various parts of the region range from 800 feet to 1,300 feet. One thousand feet is taken as a probable figure. The base of the formation has already been described. The top is exposed at a number of places. In most places, it underlies the calcareous, banded slate member of the Goose Tickle slate with apparent conformity. The contact is considered a disconformity since a lithologically unique group of strata (Northwest Arm formation) is intercalated between the Goose Tickle slate and the underlying limestone in Northwest Arm.

For the most part, the formation is pure limestone (see analysis, p. 33) which is very hackly and weathers to a rubble-like artificially crushed stone. Although zones of distinctly bedded limestone were observed at several places, bedding is usually not easily seen, the outcrops having rounded forms (Fig. 2). The most unique lithologic feature is a zone of dark grey to black, hackly limestone which is locally fissile or slate-like and contains occasional beds of grey limestone which weather chalky white. Such a zone, outcropping in Little Arm, supplies the natural road material used at St. Anthony.

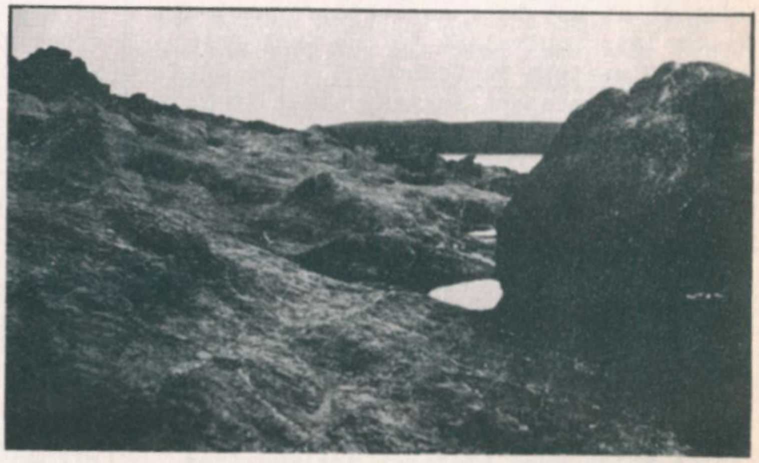

Fig. 2. Hare Island limestone on the shore of Hare Island showing the hackly, rounded forms it assumes when weathered.

The Hare Island limestone contains a fauna of cephalopods, gastropods and brachiopods. Unprocurable straight cephalopods, up to five inches in diameter at the largest septum, were observed in Little Arm and Southern Arm. Of the fossils collected, Dunbar has identified the following:

Aporthophyla aurora, Billings
Maclurites acuminatus, Billings
M. ponderosus, Billings
Archeoscyphia minganensis, Billings
Cyrtonybyoceras haesitans, Billings?
Euconia sp.?

Most of these fossils are common in the Table Head series (Chazy) of the west coast and Dunbar believes that all occur in it. Aporthophyla aurora is a Table Head guide fossil. Thus in fauna as well as lithology, the Hare Island limestone resembles the Table Head series with which it is correlated.

Northwest Arm Formation

This formation receives its name from exposures in Northwest Arm of Hare Bay where it is intercalated between the Goose Tickle slate and the underlying limestone. Its thickness appears to be 750 feet, but two facts render this figure uncertain. In the first place, the top of the formation was not observed and has not been precisely located; and secondly, it is impossible to determine the effect of crumples and minor folds which affect the formation. Its probable thickness is taken as 500 feet. There appears to be a disconformity at the base of the formation, for a sandstone near the base contains limestone cobbles which appear to have been derived from the underlying formation.

The formation is characterized by a diversity of rock types that is unique in the Hare Bay area. It consists of several kinds of slaty shale with intercalated beds of grey limestone, grey to deep-brown sandstone and chert. Abundant beds of chert are the most unusual feature. Individual beds are brownish red, black or green in color and reach a maximum thickness of ten feet. The other rocks have certain peculiarities also. The shale is in part calcareous and of various colors, a glossy green slaty shale being particularly characteristic. The sandstone is ill-sorted and commonly quartzitic. The limestone which occurs in beds a few inches to a few feet thick is hard and in many places slabby, although hackly beds and shaly beds were observed.

The stratigraphic relations and correlatives of the Northwest Arm formation are problematical since no fossils were found. In spite of some puzzling structural details, it appears certain that the formation lies between the Hare Island limestone and the Goose Tickle slate. If this is true, there are three possibilities that present themselves: it may be the upper shaly part of the Table Head series and thus closely allied to the Hare Island limestone; it may be a local sedimentary facies at the base of the Goose Tickle slate; or it may be a separate formation, more or less equivalent to the Long Point series of western Newfoundland. The data available at present suggest that it is a separate formation. It is not similar in lithology to the upper Table Head series of the west coast (17, pp. 63-68) for that lacks sandstone and chert; and of more significance, the Northwest Arm formation appears to have a disconformity at its base as already pointed out. If a part of the Goose Tickle slate, on the other hand, the difficulty arises of explaining its localized occurrence; moreover, conglomerates within the Goose Tickle slate contain chert pebbles which were probably derived from the chert beds of the Northwest Arm formation.

Goose Tickle Slate

This formation receives its name from the exposures both north and south of Goose Tickle which is the narrow strait separating Canards Island (Goose Tickle Island) from the mainland. The formation underlies large areas around the head of Hare Bay, and the whole southwestern part of Pistolet Bay. It gives the impression of great thickness in many places but this is largely due to repetition of beds by isoclinal folds and probably by imbricate faults. It is the most incompetent formation in the Hare Bay area. In Spring Arm, the thickness is 2,000 feet, and this is given as a probable figure for the formation as a whole. It is not certain that the whole formation is present there and the thickness may be closer to 5,000 feet. Murray gave the thickness as 1,860 feet (13, pp. 20-47).

The formation rests disconformably on the Hare Island limestone, except in Northwest Arm of Hare Bay where the Northwest Arm formation is intercalated between them. A conglomerate consisting of limestone pebbles and cobbles in a slate matrix was observed near the base in Pistolet Bay and on the mainland north of Hare Island. At the top, there is a more or less abrupt transition to the Maiden Point sandstone. Along the south shore of Hare Bay, this is marked by beds of quartz conglomerate which carry pebbles and boulders of limestone.

The Goose Tickle slate consists of several distinct members. The basal member may be described as banded slate or pencil slate. It consists of hard, calcareous shale with silty or fine sandy layers. The bedding is easy to see because adjacent beds are different shades of brown. Where slaty cleavage is well developed, the rock breaks into prismatic or pencil-shaped fragments, the sides of which are controlled by the cleavage and bedding directions. Banded slates outcrop extensively in the northwestern part of Hare Bay and at three places in Pistolet Bay. They are less crumpled than the succeeding members, but this is not so much due to the superior competency of the banded slates as to the fact that the competent limestone underlying them has transmitted thrust movement. The thickness attains several hundred feet.

Overlying the banded slates, and

composing most of the formation, are strata which can be conveniently referred to as the slate and limestone member. Except for several conglomerate horizons, it is rather uniform from place to place, consisting of grey to black shaly slates with occasional beds of brown-weathering sandy limestone up to four feet thick and scarce but thicker beds of calcareous sandstone. The member is highly incompetent and is much crumpled and sheared. There is one clearly marked conglomerate horizon in its lower part. This is lithologically constant and easily recognized wherever seen. It provides a useful horizon marker in the northwest part of Hare Bay and in Pistolet Bay. It is a coarse conglomerate containing partially rounded fragments of limestone, hard slate and chert. Pyrite nodules are numerous in it and these form rusty patches on the outcrop. Individual conglomerate beds do not exceed 15 feet in thickness but several beds are usually present, separated by silty slates with coarse sandy lenses. The sandstone lenses are cross-bedded in places. The only beds which might be confused with this conglomerate are intra-formational conglomerate beds composed of limestone blocks in a slate matrix. These are local in occurrence and occupy various horizons.

Volcanic rocks are intercalated with the Goose Tickle slates at two places (see Plate I). In Pistolet Bay, they are dark tuffs, breccias and pillow lavas similar to those in the succeeding strata. On the south shore of Hare Bay, two flows were observed, the thicker one 30 feet thick. They are different from the other volcanic rocks in being coarsely crystalline in their central part. Near the middle of the thicker flow, there is a sharply bounded ten-foot band of rock containing plagioclase crystals over one inch in length. Hand specimens of the rock resemble some phases of diabase and if it were not for a tuffaceous, fine-grained top, the whole mass would have been considered intrusive. The original rock appears to have been intermediate between andesite and soda trachyte. The rock is now composed of albite-oligoclase, chlorite, quartz and apatite, with abundant, fine-grained secondary calcite and chlorite and numerous euhedral pyrite crystals.

No fossils were found in the Goose Tickle slate and therefore its age is a matter of inference. It is here correlated with the Humber Arm series, part of which it resembles in lithology (5, 17).

Maiden Point Sandstone

The Maiden Point sandstone receives its name from the section exposed along the south shore of Hare Bay between Spring Arm and Cow Point. The same strata outcrop around St. Anthony Harbour and form the coast from there northward to St. Lunaire Bay. The estimated thickness of 6,000 feet is considered a conservative minimum. There appear to be 6,750 feet of strata in the type section, and the exposed thickness must be increased by an unknown additional amount, for the top part of this section lies beneath the sea. The estimated thickness is arbitrarily diminished to allow for minor duplications of strata which have been observed at several places and which are to be expected in a region of close folding such as Hare Bay. The lack of well-marked horizons in the Maiden Point sandstone makes such duplications difficult to find and evaluate.

The Maiden Point sandstone overlies the Goose Tickle slate. In Hare Bay, the base of the former is marked by conglomerate beds which contain limestone cobbles as much as one foot long. The cobbles are like the Hare Island and Southern Arm limestones which supplied boulders for conglomerates in the underlying formation. Their presence in the Maiden Point sandstone is not considered to indicate an important stratigraphic break, but rather the uplift of a neighbouring land area which was already undergoing erosion. The top of the Maiden Point sandstone lies beneath the sea and has not been observed. The Ireland Point volcanics, here considered as a volcanic member of the Maiden Point sandstone, are separated from the sandstone by a fault.

The Maiden Point sandstone consists of grey-green, pebbly sandstone with beds of shale having various colors. Some of the shale is lustrous black, maroon or red, but for the most part, it is some shade of grey or green. The sandstone was deposited on land or very close to shore. It is ill-sorted everywhere and conglomerate beds are common. At some places, conglomerate grades upward into sandstone within a single four- or five-foot bed. In some cases, channels had been cut in one bed before the succeeding one was laid down.

Both lava and tuff are intercalated with the Maiden Point sandstone, but tuff is more abundant (pp. 18-19). The distribution of volcanic rocks which is shown on Plate I, indicates that volcanic activity was a local phenomenon. There are no volcanic products in the Maiden Point section unless some of the shales contain ash. Around Pistolet Bay, on the other hand, tuffs and flows run to the very base of the formation. This indicates a center of eruption north of Hare Bay, a conclusion which is supported by the fine display of pillow lavas in the sea cliffs between Raleigh and Kirpon. Daly has described the pillow lavas at Kirpon (6).

The Maiden Point sandstone is correlated with the Humber Arm series, to part of which it bears a close resemblance in lithology. The pebbly sandstone, variously colored shales and intercalated volcanics in the two cannot be distinguished apart (5, 17). Paleontological proof of the correlation is lacking.

Ireland Point Volcanics

Pillow lavas, tuffs, and breccias aggregating 2,000 feet in thickness form Ireland Point. They are in fault contact with the Maiden Point sandstone along the south and west shores of the point as shown in Fig. 4, p. 13, and are separated from the Goose Cove schist by a fault at the mouth of Ireland Brook. The latter fault is small, for the Ireland Point volcanics are similar to volcanic members of the Goose Cove Schist, and in places there appears to be a gradual transition from them to typical schist.

The Ireland Point volcanics are similar to those of the Maiden Point sandstone. Scarce beds of pebbly sandstone like those of the latter are present also. For this reason, the Ireland Point volcanics are mapped as part of that formation and are considered a volcanic member which has been thrust into its present position.

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STRUCTURAL GEOLOGY

GENERAL STRUCTURE OF THE HARE BAY AREA

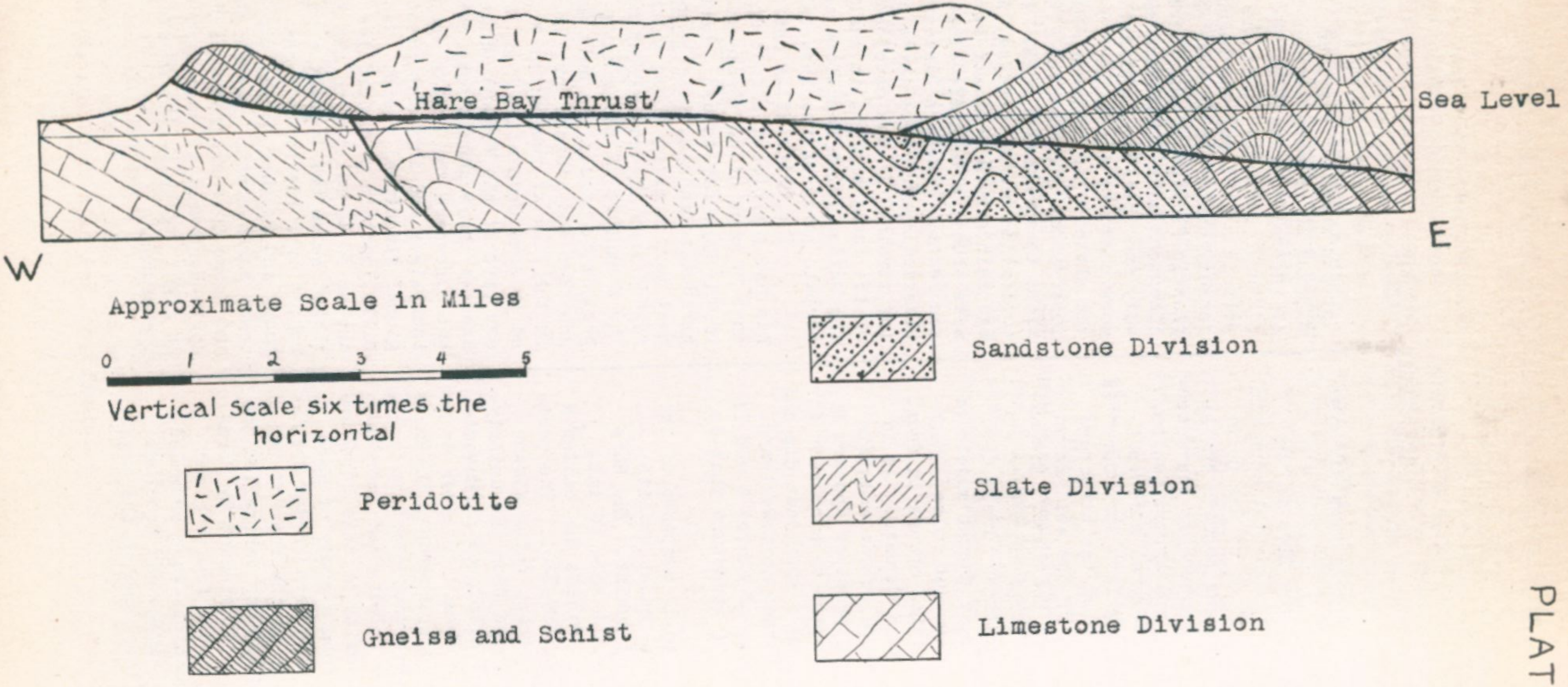
The Hare Bay area lies in the northern part of the Appalachian mountain system, within a few miles of the point where that system plunges beneath the Atlantic ocean. The structure is characterized by close folding and thrust faults, both of which have a general northeast-southwest strike. "Highland structure" is the best name to describe the structure for it resembles that of the well-known Northwest Highlands of Scotland. Low-angle thrust faults of large magnitude are the most important feature. These have cut the rocks into great thrust sheets or *decken* which have clean-cut soles. High-angle, imbricate faulting occurs in front of and beneath the main thrusts. As in other parts of the Appalachian mountain system, the deforming pressure appears to have acted from southeast to northwest for the thrust faults have a southeast dip and many folds are overturned northwestward. The structure sections of Plates I and II illustrate the kind of structure that is present.

The main *decke* is composed of the White Hills peridotite sheet and its aureole of gneiss and schist. The Hare Bay thrust, which is the sole of this *decke*, is what Bailey Willis has called a strut thrust (19, pp. 229-230). The peridotite and adjacent rocks, being strong formations, were sheared from the underlying weaker rocks and displaced northwestward with respect to them. In order to accommodate the fault displacement, the rocks beneath the fault were compressed an equivalent amount by folding and imbricate faulting. The complexity of this structure can be appreciated from a study of Hare Bay where the *decke* has been eroded away. The massive limestone at the base of the series is competent and has controlled the structural features. It yielded by forming open folds and thrust faults about which the other formations were crumpled.

Both flow cleavage and fracture cleavage have been developed in the argillaceous rocks of the area. The former, dipping 30 or more degrees southeastward, is generally present in the Goose Tickle slates. Commonly it is the only consistent structure in them, the bedding being intensely contorted or even obliterated by plastic flowage of the slate. The thin limestone beds within the slate occasionally show perfect isoclinal folds, but more commonly are broken up by flowage of the slate. The fragments have more or less random orientation, like the inclusions in an igneous rock. In spite of the contortion of the bedding, the flow cleavage maintains a constant structure over wide areas, with a dip close to 45 degrees southeast. Fracture cleavage occurs in plastic layers where there has been shearing strain. It was developed along some of the fault planes, in shaly horizons of the Maiden Point sandstone and even in certain parts of the Hare Island limestone.

The White Hills peridotite sheet has had a profound effect upon the structure of much of the *decke* which is soled by the Hare Bay thrust. Because of the peridotite masses, this *decke* is for the most part a rigid block which was less folded than the underlying formations. The structure of the banding within the peridotite masses, as well as that of the gneisses and schists surrounding them, is in the form of two basins which are affected by some undulation. In the northwestern part of the Western White Hill, the axes of these undulations strike northeast, but elsewhere the strike wraps around the intrusives and is independent of the regional structural trend. East of the White Hills, certain peculiarities of structure appear to be related to the St. Anthony thrust which has brought a higher *decke* of schist over the other rocks. At St. Anthony and further north, the structures trend north-south. Between St. Anthony and Goose Cove are numerous folds having a north-northwest to west-northwest trend at right angles to the general regional structures.

PLATE II



Idealized structural cross section north of Hare Bay

White Hills Peridotite Sheet

The peridotite which forms the White Hills and two smaller masses west of Howe Harbour was originally a continuous intrusive sheet. The thickness of the sheet remaining is estimated at 2,000 feet, but its original thickness may have been much greater since erosion has completely removed the roof and an unknown amount of peridotite. It has cut through the sheet itself along the northwest-southeast troughs now occupied by Ireland Brook and Howe Harbour. The sheet is concordant with the floor rocks which are hornblende gneiss near the contact and green schists farther away. The Sea Mountain mass is in contact with unmetamorphosed Goose Tickle slate, but this appears to be a fault phenomenon, the Sea Mountain mass being a klippe or outlier which is floored by the east-dipping front of the Hare Bay thrust.

The sheet is preserved in two structural basins corresponding to the eastern and the western White Hills. The metamorphic rocks surrounding the basins are locally much contorted but near the contact they dip beneath the peridotite at 50 degrees or less. Most commonly the dip is close to 25 degrees, but along the axis of the embayment on the northern boundary of the Western Hills it is horizontal. The intrusive itself has pseudo-stratification in the form of bands of dunite and pyroxene-poor peridotite. This banding is affected by undulations but generally conforms to the basal contact.

The structure of the peridotite is largely independent of the regional structure. The basins do not have a northeast-southwest elongation such as would be expected if they had been formed by the same forces which developed the regional structure. Only in the western part of the White Hills were folds in the peridotite banding observed to be in accordance with the regional structure. The significance of this appears to be that the structure of the sheet was for the most part assumed prior to the regional deformation. The original sheet may have had down-bulges corresponding to the present basins and thus have been a yet-undescribed kind of intrusive body. Great mafic and ultramafic sheets such as the Duluth gabbro and the Bushveld norite have depressed their floors giving rise to intrusive bodies known as lopoliths. The problem here is to explain why only parts of the floor subsided. It is conceivable that this was accomplished because of the weakening of the floor around the conduits through which the magma rose from below.

The Hare Bay peridotite masses are similar in many respects to those composing the Bay of Islands complex (5), and the explanation of one helps to elucidate the other. In the Bay of Islands region, a great ultramafic sheet (or sheets) has been thrust westward and segmented by transverse tear faults. There is no evidence for a tear fault between the eastern and the western White Hills. It is reasonable to suppose that if such a fault had formed it would have followed a course between the two basins. It may be that similar structural basins have controlled the position of the great tear faults in the Bay of Islands complex.

High-angle Faults

All faults which dip at 35 degrees or more are here classed as high-angle faults to distinguish them from flat thrusts like the Hare Bay thrust. The former are of several kinds, but the most common are thrust faults like the Brent Island, Little Arm and Hare Island faults which are of a clearly defined type. They strike northeast to north-northeast and dip 35 to 60 degrees southeast. The fault planes are characterized by intense shearing, brecciation, and drag folding.

The Brent Island fault, which is the best-known example of the type, dips 55 degrees southeast and has a throw of 2,500 feet. The slate of the footwall has been isoclinally folded and the hanging-wall limestone has been dragged downward along the fault plane forming a narrow anticline next to the fault. This drag anticline is a few hundred feet wide in most places, but on Brent Island the axis is one-quarter mile southeast of the fault and in it the oldest rocks of the region (Brent Island formation) are exposed. The Little Arm thrust dips 60 degrees southeast and the fault plane as exposed in Little Arm is a zone of intensely sheared slate with blocks of quartzitic sandstone and one block of pure, grey limestone, fifteen feet square, which were dragged up along the fault. The same fault crosses Spring Island in a pronounced gully on opposite sides of which a synclinal axis is displaced nearly a

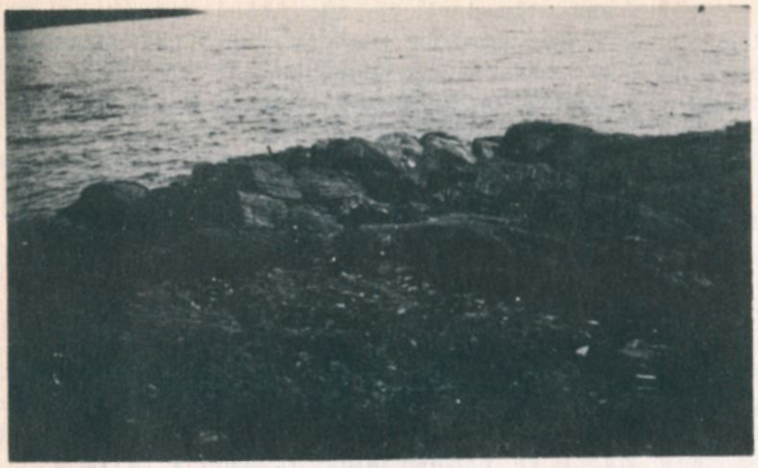


Fig. 3. Drag fold and fracture cleavage in the Maiden Point sandstone developed above a small thrust fault in Four Harbours; looking northeast.

quarter of a mile. The Hare Island thrust dips 40 degrees southeast and a slice of the Northwest Arm formation has been dragged up along it.

A number of small faults of the same type were observed and there are probably others which were undiscovered. The accompanying photograph (Fig. 3) shows the hanging wall of an example in Four Harbours. The fault crops out at the left margin of the picture and dips to the right. The overturned drag fold in the sandstone, together with the development of fracture cleavage in the shaly bed, is characteristic. Three similar faults are suspected along the south shore of Pistolet Bay because of repetition of horizons of the Goose Tickle slate and because of the presence of the Northwest Arm formation (?) in three places. The juxtaposition of the various members cannot be explained by folding. The faults are about a mile apart, the middle one passing through Triangle Point. Since they were not definitely located, they are not shown in Plate I. The faults on Schooner Island and Burnt Cape, which Richardson has described (12, pp. 873-876) appear to be of the same type.

Low-angle Faults

Although thrust faulting has long been recognized as an important feature of Newfoundland geology, the importance of

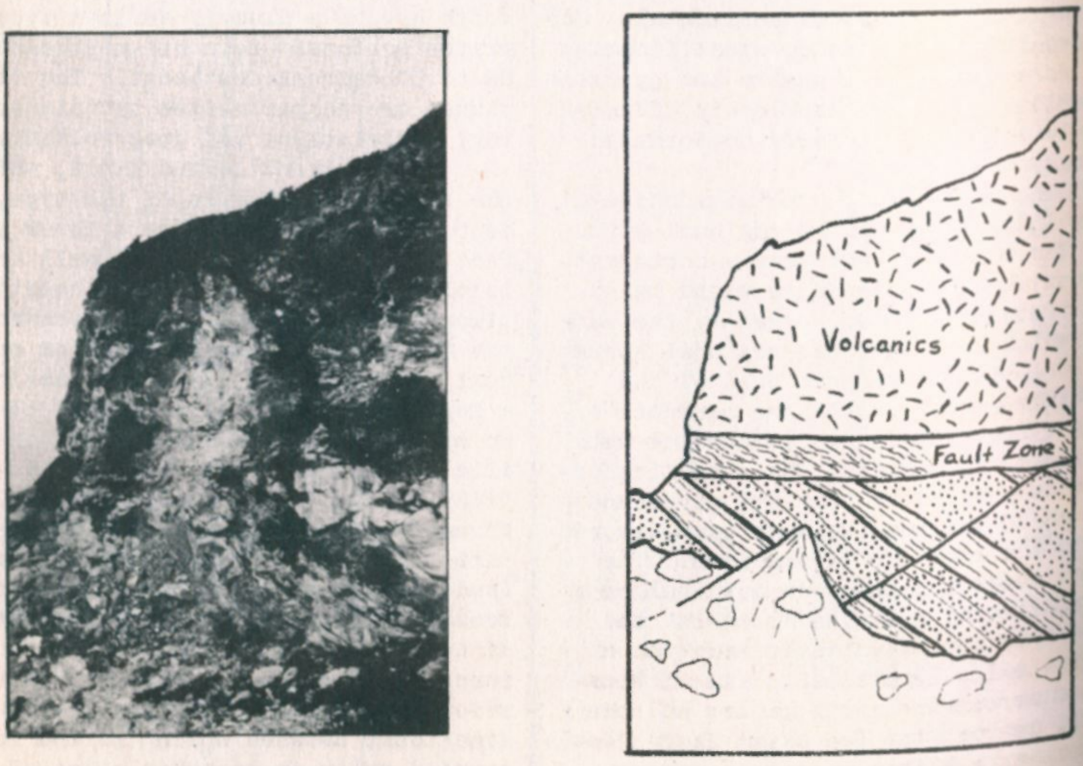


Fig. 4. Hare Bay thrust exposed at the end of Ireland Point; looking north.

nearly flat thrust faults has only recently been demonstrated. The few which have been described up to the present time compare in magnitude with those of the Northwest Highlands of Scotland and parts of the northern Rocky Mountains. They are similar to the Bannock, Lewis, Moine and other well-known thrusts of these regions. The Lewis Hills thrust south of Bay of Islands was described by the writer in 1935 (5, pp. 22-23). It is nearly flat and has a minimum displacement of six miles. Recently A. F. Buddington and H. H. Hess have discovered similar faults north of Bay of Islands (2). The present study indicates that there are three in northern Newfoundland. The best known of these is the Hare Bay thrust which has a horizontal displacement exceeding eleven miles.

An excellent opportunity of studying the Hare Bay thrust is afforded by the rugged northern shore of Hare Bay. For eleven miles west of Ireland Point, the fault is close to sea level and is well exposed in the wave-cut cliffs at many places (Fig. 4). It must be younger than the high-angle thrusts since it cuts across them and is not displaced. The fault plane is a shear zone consisting of breccia or slaty gouge which has fracture cleavage dipping gently toward the southeast. The footwall is Hare Island limestone on Grey Island, but elsewhere is Goose Tickle slate and Maiden Point sandstone which are cut by numerous diabase intrusions. Exposures of the footwall rocks are confined to a narrow belt near sea level, although the strata strike inland. The hanging wall, exposed in the higher land above them, is greenstone schist, hornblende gneiss and volcanics which have a totally different strike and dip.

High sea cliffs mark the fault place at the shore as far west as Locks Cove, but along the low-lying shore of Northern Arm the trace swings inland along the flank of Locks Mountain. After it leaves the shore, its course is hard to follow because of forest covering and complicated structure at the front of the *decke*. The trace appears to curve back through the low land north of Locks Mountain and across the northern end of Howe Harbour, leaving the Sea Mountain peridotite mass as a *klippe* resting on Goose Tickle slate. This conclusion is in accord with the lack of metamorphism surrounding the Sea Mountain peridotite, and with the occurrence of the peculiar limestone-slate-chert conglomerate on the shore of Northern Arm and the two sides of Howe Harbour, as if continuous beneath the Locks Mountain gneisses and the Sea Mountain peridotite. From Howe Harbour, the fault runs northeastward toward Pistolet Bay, but it is not known whether it crosses Pistolet Bay or curves eastward. The available data suggest that it crosses Pistolet Bay passing close to the village of Raleigh. If this is the course, it helps to explain the escarpment which forms the east boundary of the marshy lowland stretching from Pistolet Bay to Northern Arm of Hare Bay, the occurrence of volcanics and serpentine in the southeastern part of Pistolet Bay, and the presence of pillow lavas close to much older limestone at Raleigh.

The St. Anthony fault appears to be similar to the Hare Bay thrust. It rises above sea level half a mile southeast of Fox Point, runs northwest as far as St. Anthony Harbour, and then turns southwest, passing well south of St. Anthony village. It has brought Goose Cove schist above Maiden Point sandstone which here contains large intrusions of diabase. The presence of the fault is indicated by the difference in strike and dip between the sandstone and the schist, by the more intense metamorphism of the schist, and by shearing, brecciation, and drag folding in the vicinity of the fault plane. That it is a low-angle thrust fault is shown by the relation of the trace to the topography and by drag folds with horizontal fold axes which occur near the fault.

What appears to be another low-angle thrust passes through Norman Cove which is about a mile southeast of Cape Norman. The writer did not examine this fault, but Richardson's description in 1863 (12, pp. 872-873) gives a clear picture of it. Since it is the first recognition of a low-angle fault in Newfoundland, his description is reproduced verbatim: "The visible breadth of the black limestones and shales [Division N] is about twenty yards; and on the southeastward side they are overlapped by bluish-grey limestone, between which and the black beds there appears to be a fault, with an underlie to the southeastward at an angle of

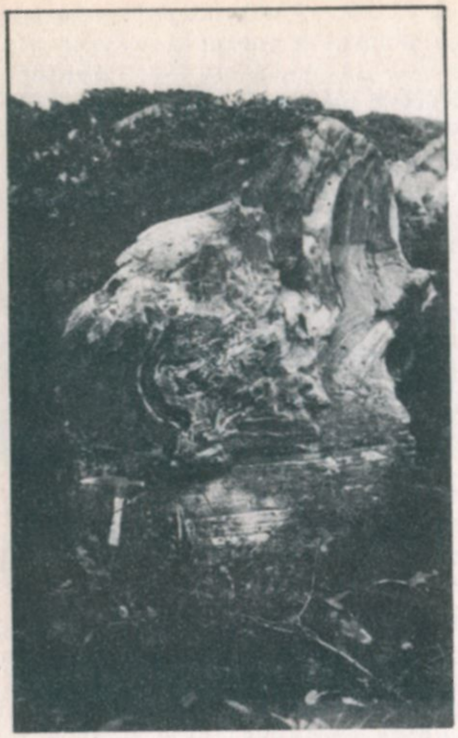


Fig. 5. Minor horizontal thrust fault in Goose Cove schist, near Goose Cove.

ten degrees. This limestone presents a confused and ragged surface, on which no evidences of stratification were observed for a breadth of three quarters of a mile, and only occasional obscure indications of stratigraphical divisions for a quarter of a mile farther. These obscurely marked beds [Division M] dip at angles varying from sixty to ninety degrees, and sometimes on one side and sometimes on the other of the strike; which, with many irregularities, is, on the average, about N. E." Richardson here shows a keen appreciation of the structural complexity of the front part of the *decke*, a feature which is characteristic of low-angle faults. The contortions may be similar to those above the small thrust fault shown in Fig. 5. The fault plane passes close to the hammer head, and the hanging wall has moved toward the left. The back folding visible at the top of the photograph appears to be due to the plowlike action of the hanging-wall block.

Folds

Folds are less prominent than faults in the Hare Bay area because many of the folds are tightly closed or even isoclinal. A study of cross bedding, graded bedding, channelling, flow cleavage and fracture cleavage is useful and sometimes necessary in working out the structures. The axial planes of the folds most commonly strike northeast and dip southeast at angles of the order of sixty degrees. Many folds are overturned so that the predominant dip of the strata is southeast.

The various formations have yielded to folding in characteristic ways. The massive limestone lies in open folds with gentle dips everywhere except in the vicinity of faults where dips are high and in places overturned. The Goose Tickle slate is intensely crumpled and the Maiden Point sandstone is tightly folded at several places. The Goose Cove schist and hornblende gneiss are much crumpled on a small scale, but large folds in them appear to be rare (Figs. 6 and 7). The peridotite displays gentle folds and minor crumples (Fig. 8). The small folds of the area are drag features accessory to larger structures. Numerous zones of crumpling in the Goose Cove schist appear to be related to faults. The large drag folds on the north shore of Cremaillere Harbour are probably related to the St. Anthony thrust

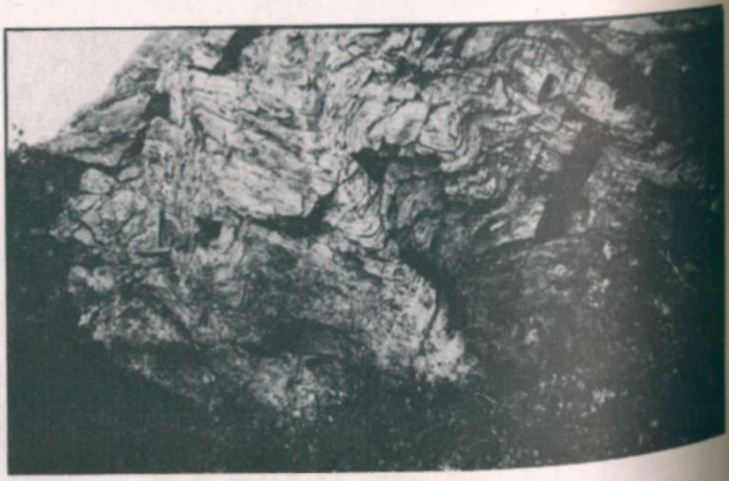


Fig. 6. Drag folds in Goose Cove schist, half a mile west of Goose Cove. Overturning is southwestward at right angles to the regional structural trend.

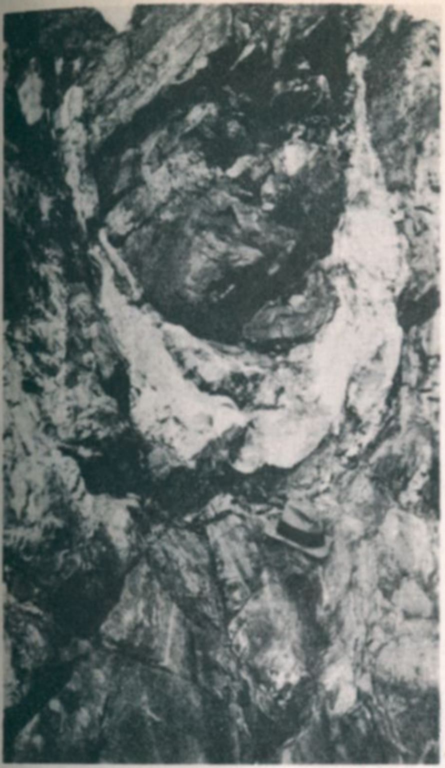


Fig. 7. Isoclinal syncline near Fichot, looking northeast. The dark rock is hornblende gneiss; the light, a marble bed which is much thickened along the fold axis.

which underlies the shore at no great depth. The same is true of the folds around Goose Cove which do not conform to the regional strike (Fig. 6). As already suggested, these appear to result from the shoving in of the decke soled by the St. Anthony thrust.

TIME OF THE OROGENY

The time of orogenic movements in western Newfoundland is in dispute. Post-Mississippian (Appalachian?) deformation is present, but the evidence is clear that the main orogeny came some time between the Ordovician and Mississippian (17, pp. 12-16; 10, pp. 17-20; 5, pp. 7-9). Both Taconic (late Ordovician) and Acadian (late Devonian) orogenies have generally been postulated by analogy with the maritime provinces of Canada and because of a supposed angular unconformity between the Ordovician and Silurian in Notre Dame Bay. Recently Heyl has shown that the supposed unconformity at the base of the Silurian

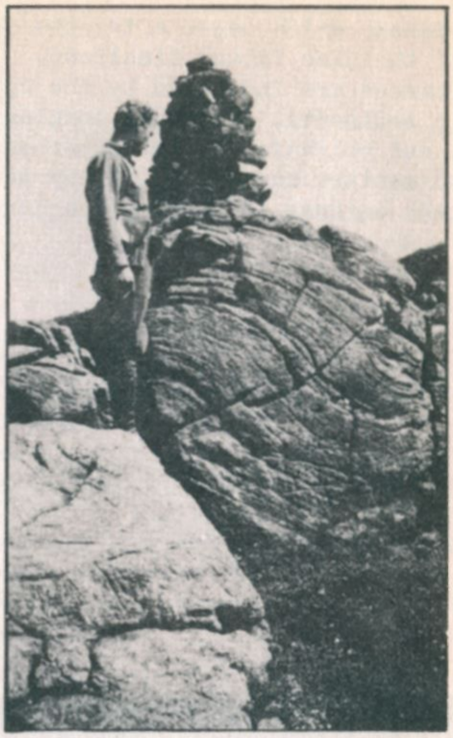


Fig. 8. Fold in peridotite foliation near the northwestern boundary of Western White Hill; looking east.

does not exist and has advanced a strong argument for Caledonian (late Silurian) orogeny (10, pp. 17-20).

Unfortunately the deformation in Hare Bay cannot be dated more precisely than between middle Ordovician and Devonian. It involves all the bed-rock formations within the area, but the youngest of these, of which the age is determined by fossil evidence, is the Hare Island limestone (Chazy). On the other hand, it preceded the deposition of the plant-bearing beds of Cape Rouge and Groais Island which lie twenty miles south of the area. These beds were discovered by Murray to be unconformable on the older Paleozoics and pronounced upper Devonian by J. W. Dawson on the basis of the plant fossils (13, pp. 41-44). Taconic or Caledonian orogeny will explain the data equally well. The problem may be solved when the age of the youngest beds involved in the deformation is established on fossil or radioactive evidence. These youngest beds appear to be the great volcanic series forming Cape Bauld peninsula.

Whatever the date of the main orogeny, it was preceded by crustal disturbances which began after the deposition of the Hare Island limestone. The disturbances are indicated by the coarse clastic sediments, recurrent conglomerate zones, and volcanics in the upper part of the sedimentary succession. They were sufficiently intense to develop fracture cleavage in the limestones by Maiden Point time. This is proved by the fact that limestone boulders in the conglomerates of that formation have fracture cleavage which runs in various directions and must therefore have been present in the boulders when they were laid down.

PETROLOGY

IGNEOUS ROCKS OF THE HARE BAY AREA

Numerous kinds of igneous rock occur in the Hare Bay area. The volcanic rocks include basalt, andesite, trachyte and dacite. Peridotite, associated with dunite, pyroxenite, and hornblendite, forms the thick White Hills sheet and several smaller sills. Coarse diabase forms stocks and laccoliths as well as numerous small intrusions. Dyke rocks include syenite and diabase, the latter grading to basalt and syenite pegmatite. In addition, there are metamorphosed intrusions which appear to range from gabbro to granite.

The igneous rocks are all post-middle Ordovician in age. They are thought to belong to a single igneous cycle which is probably late Ordovician. The cycle began with volcanic eruptions and culminated in a complicated intrusive phase. For convenience of description, the rocks may be divided into those which preceded the ultramafic intrusion and those which followed it. The former lie within the contact-metamorphic zone of the White Hills sheet, and their original mineral composition and structural relations are obscured by the metamorphism. They appear to be sills, dykes and small stocks ranging from gabbro to granite in composition. The post-ultramafic intrusives are divisible into an earlier diabase and a later syenite.

Volcanic Rocks

Volcanic rocks are confined to the upper part of the stratigraphic section. They occur in the Goose Tickle slate and all the overlying formations. The main eruptive center appears to have been northeast of Hare Bay, because the flows are most numerous in the northern part of the area, and in the White Hills *decke* which was overthrust from the east. Around Pistolet and St. Lunaire Bays, lava flows occupy horizons which lack volcanic members farther south. It is likely that volcanic ash is a constituent of the sediments in the latter region but this has not been proved.

The volcanic rocks include massive flows, pillow lavas (Fig. 9), tuffs, and breccias. Most of these are grey or greenish in color, but some are brick red in the outcrop. The grain size is generally uniform and fine but porphyritic textures were seen at several places and one very coarse flow was observed (p. 9). Vesicular, amygdaloidal and spherulitic structures are present in the finest grained rocks.

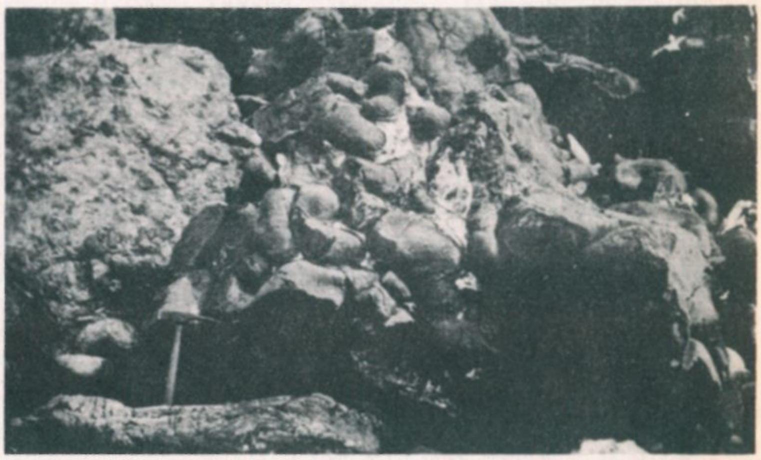


Fig. 9. Pillow lava on the west side of Ireland Point. The white material between the pillows is vein calcite.

The general name greenstone is appropriate for the volcanics since most of them have been much affected by hydrothermal alteration. Basalt, andesite, trachyte and dacite appear to be represented, but the secondary alterations make petrographic classification uncertain. Commonly the rock is a fine-grained aggregate of actinolite, chlorite, epidote, and secondary albite, with or without calcite, and a little quartz. They are cut by veins of calcite, epidote, epidote-albite, epidote-chlorite-albite, and albite-chlorite-quartz. Apatite and leucoxene pseudomorphs after ilmenite are sometimes present. Secondary euhedral crystals of pyrite are numerous in some of the rocks.

The association of chert with the volcanics suggest that the eruptions were submarine. This conclusion is supported by what appears to be marine limestone intimately associated with the pillow lavas of Ireland Point. This limestone is laminated and has the appearance of a chemical sediment. It is altogether different from the vein calcite which is present also. The beds wrap around lenticular aggregates of pillows exactly as if the limestone was deposited while the pillow lava was accumulating.

Pre-metamorphism Intrusives

These intrusives are not well understood because metamorphism has modified or obliterated their original texture and mineral composition. All occur in the Goose Cove schist and their mineral composition is like certain phases of the schist (p. 24). That they are intrusions is shown by cross-cutting structural relations and by the presence of relic textures suggestive of intrusive rocks. The bodies appear to be dykes, sills, and stocks which are less than 75 feet across. Their composition ranges from gabbro to granite, although petrographic classification is somewhat uncertain because of the abundance of secondary minerals. The salic intrusives are altered in the same way as the arkosic sandstones; the mafic intrusives, in the same way as the tuffs and lava flows.

Peridotite, Dunite and Pyroxenite

Ultramafic igneous rocks compose the White Hills peridotite sheet and a few sills in the northern part of the area. The latter are all less than 750 feet thick and appear to consist wholly of peridotite or serpentine. Unfortunately they are poorly exposed. There is no opportunity of studying a continuous section, and the contacts are covered nearly everywhere. It is possible that several of the bodies are dykes rather than sills. The White Hills peridotite sheet is a much larger sill-like body, the roof and upper part of which have been removed by erosion. A thickness of about 2,000 feet remains. It is a pseudo-stratified intrusion consisting predominantly of peridotite but having some dunite and pyroxenite differentiates. It is very similar to the lower zone of the Bay of Islands Complex (5) except that it is totally lacking in feldspar-bearing rocks like those of the interbanded zones of the Lewis Hills mass. This may be due to a lack of such rocks in the original sheet or to the fact that they were present in the upper part which has been removed by erosion.

The sheet is more than ninety percent peridotite, the banding of which is due to a difference in the proportion of pyroxene in adjacent layers (Fig. 10). The bands are parallel to the floor of the intrusion and appear to have resulted from magmatic differentiation after emplacement. In most places, the difference in pyroxene content between adjacent bands is so slight that the rock is banded peridotite; but in some places, the differentiation process has formed dunite bands from a few inches to some tens of feet in thickness. Some one-inch to six-inch pyroxenite bands appear to have been formed in the same way, but this is uncertain because of their petrographic similarity to narrow dykes of pyroxenite which cross the banding and are evidently intrusive.

The ultramafic rocks show the

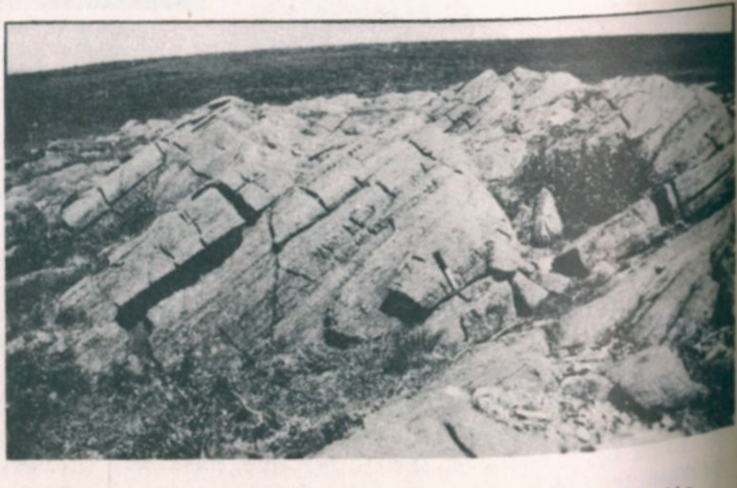


Fig. 10. Banded peridotite in the western White Hill. The thin dark bands are very rich in pyroxene.

effects of dynamic metamorphism. Although the original texture of all of them appears to have been hypidiomorphic, it is now more or less obliterated by granulation and re-crystallization. Crystalloblastic texture and augen structure are generally present in thin sections. Outcrops and hand specimens reveal the dynamic metamorphism by a secondary foliation which is parallel to the primary banding (Fig. 8), and by the presence of warped pyroxene crystals.

The petrography is similar to that of the Bay of Islands complex and no detailed description of rock types is given here. Petrographic descriptions accompanied by chemical analyses will be found in the writer's description of the Bay of Islands complex (5). The dunite and peridotite are identical with those of the Bay of Islands complex except that they are less serpentinized. The former is a forsterite-picotite rock and the latter a forsterite-enstatite-diallage-picotite rock with enstatite preponderating over diallage. Both are somewhat serpentinized, but serpentine amounts to less than ten percent in several thin sections studied. The minerals of both have a low tenor of iron as compared with magnesium. In the White Hills sheet, this same characteristic applies to the pyroxenite which is apparently always an enstatite rock. If hypersthenite, like that of the Bay of Islands complex, exists, it was not found, and must be scarce.

The writer has discussed the problem of serpentinization of the Bay of Islands complex (5, p. 30). It was concluded that the serpentine was formed by oxidizing aqueous solutions which probably originated as residual liquors of the ultramafic magma. They were migratory solutions, serpentinization having been accomplished after the crushing and re-crystallization of the primary minerals. Serpentinization of the White Hills sheet was of the same kind. It has yielded common serpentine except locally where chrysotile (asbestos), retinalite (resinous variety), and picrolite (fibrous variety) have been formed. The chrysotile and picrolite occur in veins, the retinalite as a lenticular mass near the Hare Bay thrust in Howe Harbour.

The chemical changes brought about by serpentinization of the Bay of Islands complex were the addition of water and oxygen to the rock. The serpentine formed had the approximate composition $4\ MgO \cdot 2\ SiO_2 \cdot 3\ H_2O$* and the author emphasized the variability of the composition of serpentine. Subsequently a new serpentine mineral having the composition $2\ MgO \cdot SiO_2 \cdot 2\ H_2O$ has been described (14). The presence of this mineral with common serpentine will explain the chemical peculiarities of the Bay of Islands serpentine. Its presence is suspected but not proved in the White Hills serpentine. Its optical properties are so close to those of common serpentine that it is not readily identified.

Veins of carbonate cut the serpentine of the Hare Bay area and, in the field, it was thought that they might be magnesite. The veins, however, are readily and completely soluble in cold hydrochloric acid and are therefore calcite. They do not indicate any leaching of magnesia during serpentinization. A few veins consisting of magnesite, chlorite, and re-crystallized serpentine are later and unrelated to serpentinization. They are evidently of hydrothermal origin.

Hornblendite

Hornblendite occurs in peridotite near the base of the White Hills sheet in Howe Harbour and also in one of the Pistolet Bay sills. The occurrence is identical in the two places; and in both, there are associated nickel minerals (p. 26). The hornblendite, much of which is chloritized to a pale grey rock, forms a migmatite with the peridotite (Fig. 11). The bands of hornblendite are anywhere from two feet to a small fraction of an inch in thickness. They appear to have intruded the peridotite. The field evidence of this is the sharp contacts of the bands and the manner in which wedges of hornblendite split peridotite bands. Each band fingers out in a short distance. A special search for cross-cutting hornblendite dykes was made but none was found.

The unaltered rock consists of brown hornblende with late-formed biotite, titaniferous magnetite, and pyrrhotite. The last three are abundant in the Howe

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*The chemical composition of antigorite is $3\ MgO \cdot 2\ SiO_2 \cdot 2\ H_2O$.

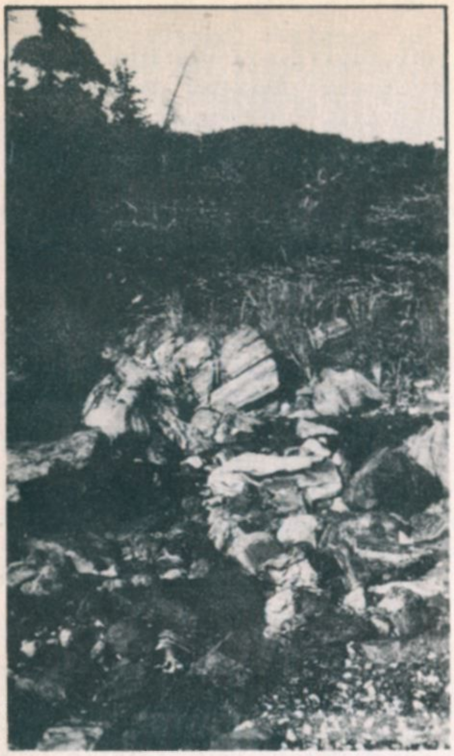

Fig. 11. Altered hornblendite (white) forming migmatite with serpentinized peridotite (black) in Howe Harbour. Nickel-bearing sulphide veinlets occur in serpentine here.

Harbour rock. They occur between or in cracks within the hornblende crystals and appear to have corroded them. Where the hornblende has been completely replaced by chlorite and titanite, the late-formed minerals within the altered rock retain the structure they assumed when they rimmed hornblende grains.

The hornblendites are probably products of contamination of a mafic magma by the peridotite wall rock. Masses of coarse-grained younger diabase occur within short distances of the hornblendites but are separated from them by the Hare Bay thrust.

Diabase Sheets, Stocks, etc.

Coarse-grained, dark diabase forms four prominent intrusions near St. Anthony, and one on the south shore of Pistolet Bay. Small, unmapped bodies of the same rock are numerous on the north shore of Hare Bay west of Starks Bight. The intrusions have the form of stocks and irregular dykes, sills, and sheets. Those which abut on St. Anthony Harbour suggest laccoliths which have been tilted about 45 degrees toward the east; this interpretation, however, is unlikely, because the eastern intrusion has gently dipping flow-bands and a horizontal basal contact exposed in the sea cliffs of St. Anthony Bight (St. Mein Bay). They may be discordant flat sheets; in which case, the areal extent of them gives an exaggerated impression of the bulk of the intrusions.

The distribution of the diabase bodies gives some indication of the time and manner of the intrusion. Those in Hare Bay are close to the Hare Bay thrust, most of them being confined to the footwall. The larger bodies near St. Anthony have a similar relationship to the St. Anthony thrust. There are too many examples in Hare Bay to consider the association with the fault fortuitous, and it is suggested that the bodies were intruded while the faulting was taking place. The bodies themselves show the effects of deformation by minor faulting and shearing, by the presence of a few warped crystals, and by the fine-scale, inconstant twinning of the feldspar. They are older than the syenite dykes which were found cutting them.

The intrusions are as coarse grained as ordinary granite over most of their area but have fine-grained chilled margins. Ophitic texture is discernible in hand specimens as well as in thin sections of the rock. The primary minerals are pale brown augite, plagioclase, ilmenite and apatite. The secondary minerals include chlorite, epidote, albite, titanite, calcite and pyrite.

Although hand specimens of the rock are fairly fresh in appearance, thin sections show considerable alteration in the form of albitization and choritization. The augite is commonly completely choritized. The plagioclases are albite and oligoclase, and are considered to be of secondary development. Patches of clear albite associated with epidote, and clear albite near calcite veins are certainly of this origin. The ilmenite has been replaced by titanite to form the familiar leucoxene pseudomorphs, many of which show the grid structure of magnetite blades generally present in the ilmenite of igneous rocks. Considerable pyrite was introduced during the alteration process. It is locally abundant in disseminated cubes, but no sulphide veins or segregations related to the diabase were discovered.

Diabase Dykes

Ten diabase dykes ranging from two feet to forty feet in thickness were observed in the Hare Bay area (Fig. 12). They are sufficiently different from the diabase just described to be considered separately. Although the two were not found in contact, it is probable that the dyke diabase, now to be described, is a later intrusive. It is much finer grained even in bodies of comparable size and the bodies have a regular dyke form. The dyke in Little Arm was traced for nearly half a mile, and in this distance, it was everywhere six feet or less in thickness. The dykes are younger than the metamorphism of the Goose Cove schist for they cut the latter and are not themselves metamorphosed. Their intrusion followed the main deformation, although they are faulted on a small scale.

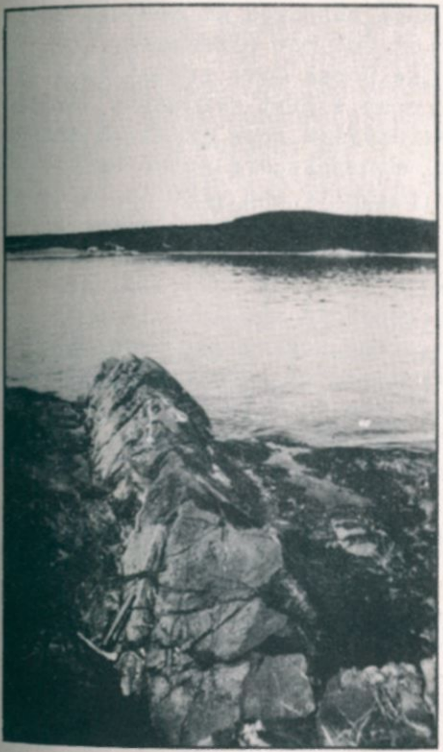

Fig. 12. Diabase dyke in Little Arm. The white veins are calcite containing a little pyrite.

Though the dykes are much altered in places, a very fresh rock was secured from one of the dykes of Goose Cape. It is a fine-grained, dark rock which weathers reddish brown. Under the microscope, it is seen to be an olivine diabase. Ophitic texture is well developed, a single augite crystal including many plagioclase laths. Equidimensional, early-formed olivine grains are scattered through the rock. Ilmenite grains are abundant and are among the last constituents to form. They are molded about the plagioclase laths and occur between, rather than within, the large, ophitic pyroxene crystals. Rapid cooling of the rock is indicated by zoned borders on the plagioclase crystals. The center of the plagioclase grains is labradorite ($Ab_{43}An_{57}$) and the borders probably andesine.

All the other specimens studied show considerable secondary alteration. Uralite, chlorite, carbonate, epidote, sericite, and secondary feldspar are the principal secondary minerals. Olivine was not observed in the rocks and it is not known whether it was once present; even if present originally, it is not likely to be preserved because it is so readily altered under hydrothermal conditions. The pyroxene and plagioclase are chloritized, uralitized, and carbonatized; the ilmenite has been replaced by leucoxene. Pyrite-calcite veins cut the altered rock and appear to have been formed by the same solutions (p. 31).

An interesting feature of the diabase dykes are segregations of albite syenite pegmatite within them. These are in the form of lenses most of which are less than a foot long. The primary minerals are brown hornblende, albite, titanite and apatite. They evidently represent a salic residuum of the diabase magma. The hornblende contains un-resorbed augite cores but has the boundaries of euhedral hornblende. The secondary minerals of the pegmatites include chlorite, carbonate, sericite, and zoisite.

Syenite Lamprophyre Dykes

Syenite lamprophyre dykes cut the Goose Cove schist and the coarse diabase at St. Anthony. They are only a few feet thick and do not appear to extend far along the strike. They have flow structure parallel to the walls which indicates that some crystals were present in the magma at the time of injection. Their intrusion occurred after the deformation of the Goose Cove schist and the emplacement of the coarse diabase. It is likely they followed the diabase dykes also.

The rock is augite-biotite syenite lamprophyre. Flakes of brown biotite are discernible in hand specimens which are grey and appear altered. Thin sections show a rather high percentage of mafic minerals, in a few places enough to make the rock shonkinite. Deep-brown biotite is slightly in excess of pale-green to colorless augite. The latter shows crystal boundaries and zoned margins. Quartz is present but ordinarily scarce as scattered grains and as myrmekite. Both orthoclase and plagioclase are present, commonly intergrown to form a perthite which appears to be of deuteric development. Titanite, apatite, and pyrite are the primary accessory minerals.

Uralitization and local introduction of much carbonate were the principal alteration processes. Alteration is slight through the main body of the rock, but there were phenocrysts in the original rock which are now completely replaced by tremolite, fine-grained green biotite, and carbonate. These minerals indicate that the phenocrysts were some mafic mineral. The shape suggests that they were olivine.

Goose Cove Schist and Hornblende Gneiss

These two rocks are described together because they compose a single contact-metamorphic aureole surrounding the White Hills peridotite. The hornblende gneiss is a high-temperature metamorphic facies close to the peridotite, whereas the schist is a lower-temperature facies farther away. The contact between the two is gradational but sufficiently distinct that it can be mapped. There are two schist and gneiss areas unrelated to the White Hills sheet but apparently of a similar origin. One is adjacent to a thick peridotite sill in Pistolet Bay, and the other in the islands at the mouth of Hare Bay. The relation of the various rocks in the latter region suggests that there is a peridotite mass beneath the sea not far east of Fichot Island.

The schists and gneisses are the metamorphosed equivalent of the upper part of the stratigraphic section. The volcanic members of the Maiden Point sandstone appear to be the portion affected, but it is possible that part of the Goose Tickle slate is involved. It is certain that some of the schists and gneisses were originally volcanic because they retain pyroclastic, spherulitic and pillow structures. Most of the well-foliated schists and gneisses appear to have been derived from fine-grain tuff or ash beds but it is possible that some were derived from calcareous shales. Chemical analysis is necessary to determine the original rock with certainty. Metamorphosed arkosic sandstone is present but scarce. Thin limestone beds, now transformed into coarse-grained marble, were observed at several places near Fichot but not elsewhere (Fig. 7).

The Goose Cove schist is a fine-grained green schist evidently derived from a well-stratified rock (Figs. 5 and 6). The principal minerals are green amphibole and epidote; chlorite and alkalic feldspar are present but rather scarce in the thin sections studied. Considerable sericite, together with other secondary minerals, has been developed in the arkosic sandstone horizons. The schist has been studied most carefully near the copper deposits at Goose Cove where the rock is amphibolite schist. The amphibole is a deep green, pleochroic hornblende.

The hornblende gneiss is a medium-grained, dark rock which is well foliated and, in places, distinctly banded. The weathered surface commonly assumes a salt-and-pepper appearance. In thin sections, olive-green to brownish hornblende is the most prominent constituent. Albite or oligoclase, which is ordinarily much obscured by weathering products, is the next most abundant constituent. Less abundant minerals include titanite, garnet, pyrrhotite, magnetite, augite and epidote. The pyrrhotite is rather abundant in some places where the rock carries traces of nickel (p. 26).

The contrast between the hornblende gneiss and the Goose Cove schist is due to a difference in grade of metamorphism. Both are best explained by assuming that they were originally mafic tuffs, possible mixed with a little clay and lime. The present mineral association in each is similar to a metamorphic facies of the gabbro suite as described by Eskola (8). According to his classification, the gneiss would fall in the amphibolite facies, and the schist in the epidote-amphibolite and the several greenstone facies. Most of the schist is in the actinolite-greenstone facies.

ECONOMIC GEOLOGY

MINERAL DEPOSITS OF THE HARE BAY AREA

The mineral potentialities of the Hare Bay area fall into three general classes: (1) Those genetically related to the peridotite; (2) The hydrothermal veins carrying base metals; (3) The sedimentary rocks. The valuable substances associated with peridotite in various parts of the world include chromite, asbestos, nickel, serpentine, talc, soapstone, magnesite and the platinum group of metals. Traces of the first four of these have been found in the Hare Bay area. Further prospecting should be guided by these discoveries and should include a search for platinum by a systematic panning of gravels along all streams flowing from the peridotite areas. The hydrothermal deposits include those of pyrite, pyritic copper (Goose Cove deposits), and a small amount of lead and zinc. The potentialities among the sedimentary rocks are limestone and slate. The following detailed descriptions of the various deposits will suggest the probability of valuable discoveries and serve as a guide to further prospecting. In the author's opinion, the limestone could be developed in a small way at the present time.

Chromite

Chromite (picotite variety) is an accessory mineral in the peridotite and dunite. Thin stringers of it occur in dunite bands at many places, but larger concentrations are scarce. Schlieren-like lenses about an inch wide and a foot or two long were seen at half a dozen places. The lenses occur singly and without apparent system. Loose fragments on the surface indicate somewhat larger concentrations. A rectangular piece of nearly solid chromite weighing about fifteen pounds was found 1 1/2 miles northeast of Three Brooks Pond. It is a glacial erratic but unquestionably of local derivation. Numerous small pieces of solid chromite are mixed with the gravel of a raised beach east of Howe Harbour (Plate I). They are scattered rather abundantly over an area 15 feet by 50 feet and are evidently a residual accumulation from a chromite lens in bedrock.

The chromite of the lenses is altogether similar to the accessory chromite of the dunite and peridotite. In hand specimens, it is shiny black; but in thin sections, it is translucent brown. The chromite from most localities is commonly opaque or nearly so, but the translucence of the mineral in Hare Bay does not indicate a low tenor of chromium. Some ore fragments from the locality east of Howe Harbour were assayed to check the amount of chromium. The assay showed 54.05* percent of chromic oxide which compares favourably with many chromite ores that are worked. It is rich enough for any of the uses to which the mineral is put.

The chromite deposits which have been found belong to the early-formed type (15, 16). This conclusion is based on the optical identity of the mineral with the accessory chromite of the surrounding rocks and the association of it with early-formed pyrogenetic minerals. According to Sampson, the early-formed accumulations do not occur in sufficient concentration to form ore (16, p. 834). It is true that the known occurrences in Hare Bay give small promise of the presence of workable deposits; but further search may uncover deposits of potential value like those of the Bay of Islands complex (18) which is extremely similar gologically. One deposit in the latter region (Bluff Head deposit) has produced over 5,000 tons in the past.

Asbestos

Cross-fiber veins of serpentine asbestos (chrysotile) cut the peridotite at many places. They may have no regularity or may occur in closely spaced, parallel planes, giving typical ribbon structure.

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*Assay by J. F. Newman, Newfoundland Government Laboratory.

In the latter mode of occurrence, the asbestos makes up ten to twenty per cent of the rock in some places. Such a proportion of asbestos suggests the possibility of economic exploitation. Only six to ten per cent of asbestos is recovered from the rock milled at Thetford, Quebec (11, p.396). The economic possibilities depend on the length and quality of the fiber and the amount of rock of ore grade.

The asbestos is of good quality, but the fiber is so short that only a low grade of the crude mineral could be produced. In most places, the veins are less than 1/16 of an inch in thickness and may have partings which make the fiber even shorter. The longest fiber was found north of Three Brooks Pond (Plate I). The veins have ribbon structure and some of them exceed 1/8 of an inch in width. A little fiber 3/16 of an inch long was secured.

The writer did not discover any place where rock approximating ore grade extended over more than a few feet in width. The structural relations of the veins north of Three Brooks Pond are not exposed and further prospecting may be justified. The veins occur where the peridotite is sheared and serpentinized. The most favorable field for prospecting is in the small peridotite bodies and near the west margin of the White Hills sheet where there is fracturing and contortion connected with the Hare Bay thrust.

Nickel

Because of the world-wide association of nickel with mafic igneous rocks, a constant search for nickel mineralization was made. Nickel was found in two modes of occurrence but neither of these is of a type to suggest the presence of valuable deposits.

Sulphides, among which pyrrhotite is prominent, are accessory minerals of the hornblende gneiss. Although they never make up more than two or three percent of the rock, they are sufficient to give it an intensely rusted surface in places. A specimen from Split Point, Howe Harbour showed traces of nickel.* Except for the presence of about two per cent of sulphides, it is similar to other specimens of the gneiss. The low tenor of nickel, together with the mode of origin of the gneiss, (p. 24) gives little encouragement that there are valuable nickel concentrations present.

Nickel is found also in peridotite close to the small hornblendite intrusions (p. 21). Richardson reported traces of nickel with this mode of occurrence in Pistolet Bay (12). A specimen of the mineralized rock from Howe Harbour, collected by the writer, contained 0.37 per cent nickel.** The observed deposits are only a few feet across and too low grade to be of value. The assayed specimen is the richest found and even this compares unfavorably with ores of the Sudbury district, Ontario, which carry from two to three percent nickel. The deposits are of interest since there may be larger concentrations of the same sort. Moreover, it is possible that metals of the platinum group are present with the nickel. Elaborate chemical or spectroscopic analysis is necessary to determine the presence of platinum.

The nickel occurs in sulphide veins which cut the peridotite within a few feet of hornblendite intrusions. There can be no question that the mineralization is genetically related to the hornblendite. It is possible that some of the nickel was derived from the peridotite since small amounts of nickel are ordinarily present in ultramafic rocks. The minerals of the veinlets are similar to those composing the mesostasis of the hornblendite, consisting predominately of pyrrhotite with magnetite and shreds of biotite. Apparently, some of the interstitial material of the hornblendite was squeezed into cracks of the peridotite. Some chlorite, like that of the hornblendite, is present in the veins. Late-phase chlorite veins which show strong banding and colloform structures are visible in thin section.

Polished sections of the ore show pyrrhotite, pentlandite, and chalcopyrite, with magnetite and ilmenite (?). Magnetite and ilmenite are the oldest minerals, occurring as rounded grains veined by silicates and pyrrhotite. Ex-solution intergrowths of the two (titaniferous magnetite), similar to those of the hornblendite, were not observed. Pentlandite, which is the nickel-bearing mineral, occurs in rather coarse grains. It is cut and apparently replaced to some extent by pyrrhotite. Pyrrhotite, as rather fine interlocking grains, constitutes most of the section. A little chalcopyrite is finely disseminated in the gangue and occurs also in some irregular silicate veinlets crossing the pyrrhotite.

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*Assay by J. F. Newman.

***ibid.*

Goose Cove Copper Deposits

Acknowledgment

This description is based on a special study of these deposits made by the author's field assistant, Kirk Stephenson. The field work and laboratory study were carried on under the author's direction.

Location and Geological Setting

The mineralized area at Goose Cove (Plate III) is located in a topographic depression running between Goose Cove and Little Back Cove. The depression separates the highland of Goose Cape (maximum elevation 333 feet) from the prominent Three Mountain mass. The highest peak of the latter rises to an elevation of 543 feet half a mile north of the main workings.

The Goose Cove Schist of the area strikes in the main northwest-southeast, and has a general dip to the northeast. Locally this trend is modified by minor folds and crumples. That the deforming pressure came from the northeast is indicated by many folds which are overturned to the southwest (p. 16). A number of small thrust faults were observed with planes dipping to the northeast at angles of 30 to 40 degrees. The angle of the thrust planes does not follow the dip of the foliation of the schist, but approximates it closely in some places (Fig. 13). The north side of Goose Cape appears to be made up of a number of small, overlapping thrust sheets about 100 feet thick. Displacement does not appear to be great along these minor thrusts. Thrusts of greater magnitude apparently underlie the entire area. Just east of the mouth of Goose Cove, at the base of a cliff 80 to 90 feet high, is a thrust fault striking northwest-southeast and dipping 25 degrees to the northeast. Above the plane of the thrust, the green schist is very much crumpled and overturned to the southwest. Below the thrust plane are well-defined beds of black and light green schist which are relatively undeformed.

The top of the Three Mountains is capped by hornblende gneiss, similar to that found around the White Hills. The gneiss is in the form of a gentle syncline and is an erosion remnant of a formerly widespread formation which probably was once continuous with the gneiss to the west.

A number of metamorphosed sills are found in the Goose Cove schist. These are best exposed at the east end of Goose Cape along the shore. They were intruded before the metamorphism of the schist and some of them have a schistose character.

Several diabase dykes cut through the schist on Goose Cape. These vary in thickness from a few feet to about 40 feet. They are almost vertical and all strike about east-northeast. All the dyke's are offset at intervals by normal faults of small displacement, which cut through nearly at right angles to the trend of the dykes.

A number of normal faults are present which strike a little west of north. They are marked topographically by long, narrow gullies up to about thirty feet in width. These gullies extend across Goose

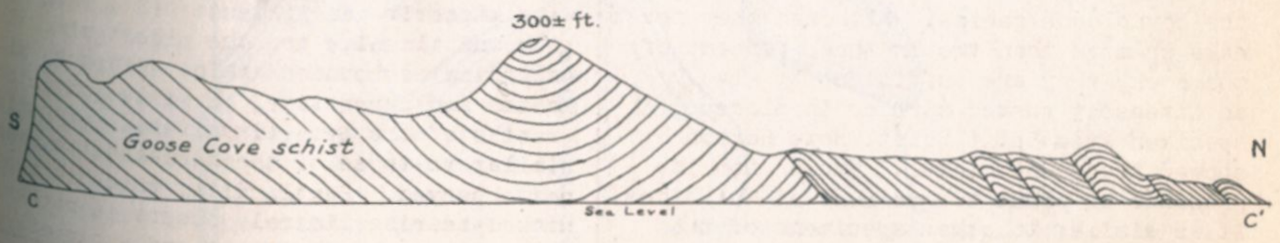
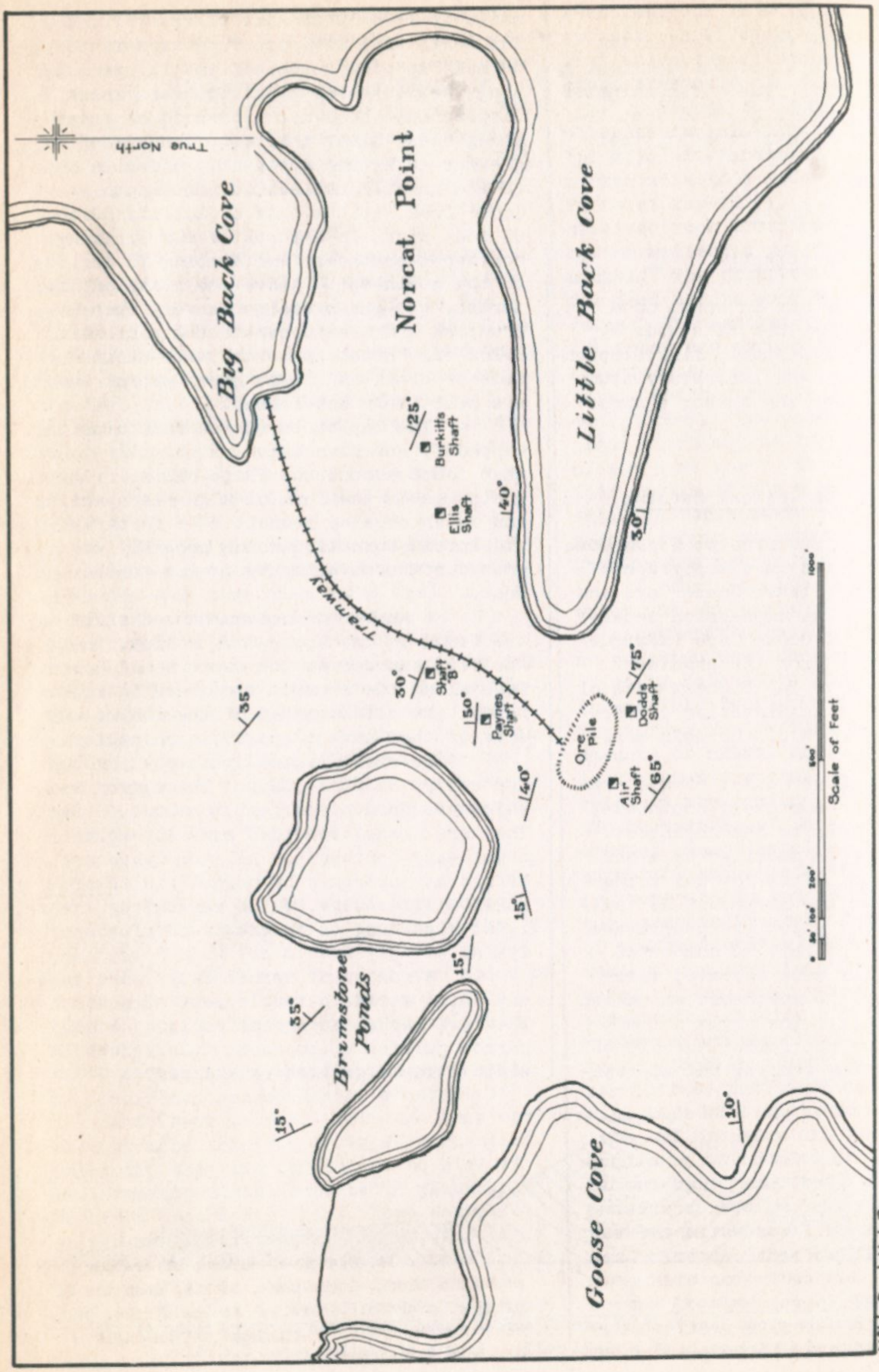


Fig. 13. Profile along line C-C' (Plate I) across Goose Cape. The northern third of this section is well exposed in the walls of a small gully. Length of section about 0.6 mile.



Nfld. Dept. Nat. Res.

MAP OF THE MINE AREA, GOOSE COVE

[See Plate I for location]

Cape and may be seen north of the mineralized area on the east side of Three Mountains. The faults responsible for the gullies appear to be small, for there are not many drag effects.

In the area of the mine workings, there is very pronounced drag folding which appears to be related to the thrust from the north. Most of the ore bodies occur in these drag folds. They trend northwest-southeast, and the fold at Dodd's shaft plunges to the northwest at an angle of 50 degrees. Ellis' shaft and Burkitt's shaft are directly on a line with a large drag fold exposed in a cliff on Norcat Point.

History and Possibilities of Future Development

The Goose Cove copper mine was opened in May, 1908, and was worked for several years under the management of Mr. Brenton Symons of London. No ore was shipped during that time as work was confined to opening shafts, constructing mine buildings, etc. The ore which was removed was dressed and piled on the property where it still remains. In 1918, Mr. Larson of Harbour Grace Shipbuilding Company visited the mine and estimated that there was about 1,800 tons of dressed ore there.

About $40,000 was spent on the property by the operators. Four main shafts were sunk on veins. The deepest of these, Dodd's shaft, is more than 100 feet deep down the slope of the ore body. In addition, several prospect holes were dug in the numerous mineralized outcrops. A tramway was built from the ore pile at Dodd's shaft to the shore of Big Back Cove where a wharf was erected for loading ore. Several buildings were erected, including a miners' barracks, shaft house and blacksmith shop. The buildings are destroyed or in bad repair at present. Only the upper part of the old workings are accessible, the shafts being full of water or loose rock to within 10 or 15 feet of the collars.

There is no likelihood that the deposits can ever be operated at a profit. The ore, when taken out, was estimated to contain from 2 to 12 per cent copper. The latter figure is undoubtedly too high except for a very small percentage of the ore. To operate the deposits profitably, large tonnages would have to be handled and the ore bodies are not large enough for this sort of operation. Traces of gold are present in several specimens of the ore, (Table II) but the amount is too small for profitable extraction.

Description of Orebodies

The location of the larger concentrations of ore is shown on Plates I and III. All but one of these occur in the Goose Cove-Back Cove mineralized area described above. The other occurs a mile north of Goose Cove, near the trail leading to St. Anthony (Assay 4 of Table II). It indicates that mineralization of the Goose Cove type was not confined to the mine area.

The ore bodies are irregular in shape. They generally follow the foliation of the schist which is much contort The thickness of the ore horizons varies greatly within short distances. The mai orebody is well exposed, the ore lying i a U-shaped mass following around a large drag anticline (Fig. 14). Each limb of the orebody is about four feet thick, bu the axis is over twice that thickness. T orebody pitches at about 55 degrees to t

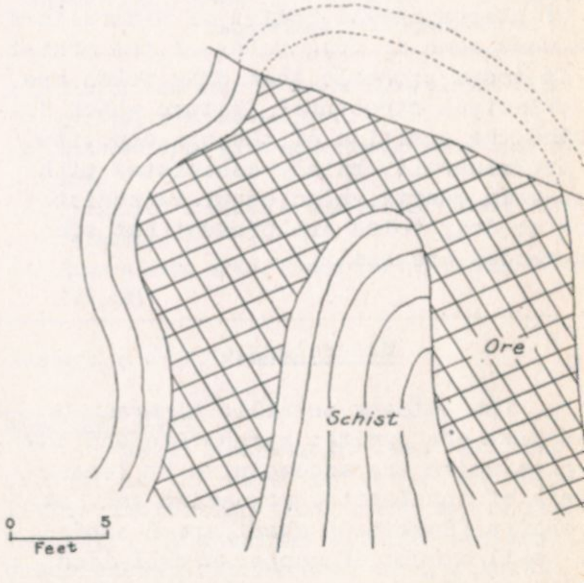


Fig. 14. Sketch of outcrop of orebody at Dodd's Shaft, Goose Cove, looking down the pitch of drag fold, parallel to the strike. The fold plunges north-northwest at an angle of about 55 degrees.

Table II*

ASSAYS OF PYRITIC COPPER ORE, GOOSE COVE

	(1)	(2)	(3)	(4)
Copper	10.18%	8.57%	4.20%	0.95%
Gold	nil	minute trace	nil	traces
Zinc	---	-----	traces	-----

(1) Massive pyrite and chalcopyrite, Payne's Shaft
(2) Massive pyrite and chalcopyrite, Burkitt's Shaft
(3) Schist showing much fine-grained disseminated pyrite and chalcopyrite, Dodd's Shaft
(4) Massive pyritic ore, one mile north of Goose Cove

*Assays by J. F. Newman.

north-northwest. The records of operation show that the orebody continues to a depth of 120 feet where work was abandoned. The width of ore at that depth was variable, running as low as a few inches in some places.

The structural relations at the other shafts are not exposed as the workings are filled with water and loose rock. Judging from written descriptions and the amount of ore removed, they are smaller than the Dodd's shaft ore body. At a number of places, small bodies of mineralized rock were seen in drag folds of the schist and it seems probable that drag folds are the principal structural feature which determine the position of the ore deposits. The ore minerals, mainly associated with white vein quartz, also occur in schist where no drag folds are present but such occurrences are small.

Mineralogy

The primary metallic minerals at Goose Cove are pyrite, pyrrhotite and chalcopyrite which are accompanied by lesser amounts of sphalerite, magnetite and, at two shafts (Burkitt's shaft and B shaft), by a small amount of copper-nickel-iron arsenides. There are no secondary minerals of any importance. The outcrops are stained by limonite and there is a trace of malachite and azurite. Limonite forms a coating on cracks in the weathered ore and also occurs as radiating stains surrounding pyrite crystals which may be observed in some thin sections. The gangue minerals are hornblende, epidote, calcite and quartz. A little chlorite and feldspar are present in some thin sections. The average copper content of the ores examined is not high. It would certainly average lower than that shown by the assays of Table II for these represent selected specimens from the dumps at the respective shafts. The specimens were selected to show mineral relationships and are of higher grade than the bulk of the ore. It was thought that assays of such material would reveal the presence or absence of gold.

The ore minerals occur as stringers and bunches in the schist, most of the stringers following the foliation of the schist. Some of the ores have a massive appearance, with pyrite, chalcopyrite, and pyrrhotite predominating. The ore minerals have replaced the schist. Residual masses of silicate are inclosed within them. The paragenesis is not clearly defined. Pyrite, pyrrhotite, and magnetite belong to the early period of mineralization. Chalcopyrite and sphalerite are essentially contemporaneous and were formed at a somewhat later stage. The cobalt-nickel-iron arsenides belong to the later stage and are probably later than the chalcopyrite. In some cases, late-formed gangue minerals have replaced the sulphides.

Genesis

The copper ores are thought to be post-folding hydrothermal replacements of the schist. The solutions rose along channels provided by the foliation of the schist, as indicated by the fact that the ore stringers generally follow the foliation. The optimum conditions for ore deposition appear to have been where the upward migration of the solutions was guided and concentrated by pitching drag folds in the foliation. It is thought that, at depth, the planes of the thrust faults observed east of the mine area cut through the schist inclosing the ores. These faults, if continuous for any distance, would provide an additional channel for the movement of solutions. The drag folds in which ore concentration has taken place are considered to be in close relation to the thrusts.

The origin of the solutions is somewhat problematical. The only igneous rocks of post-folding age are diabase and syenite lamprophyre dykes and it seems unlikely that the ores are derived directly from either of these. The small prospect a mile north of Goose Cove is near a syenite lamprophyre dyke, but this association may be fortuitous. It seems most likely that the ore-forming solutions rose from a deeper lying magma that was undergoing differentiation. This magma reservoir may have supplied the dyke material at various stages in its differentiation.

Pyrite

Pyrite concentrations of several kinds have been investigated to determine whether they carried gold. The results of four assays of typical occurrences are given in Table III. The pyrite nodules which are abundant in the Goose Tickle slate have not been assayed because they are ordinary ground-water concretions and would not carry precious metals.

The silicified zone represented by assay (1) is half a mile north of Goose Cove. It is a few feet wide and crops out at intervals over a distance of a quarter of a mile in a north 85 degrees east direction. It is a dense grey rock which weathers rusty brown. Very fine pyrite grains make up one to four percent of the silicified rock and are disseminated in the adjacent schist.

Assay (2) is on a specimen collected from one of the diabase dykes (p. 23 and Fig. 12). The specimen came from a six-foot dyke on the east shore of Spring Arm. The dyke has a rather pale greenish-grey color because of the large amount of secondary calcite and chlorite developed in it. Pyrite occurs in brilliant cubic crystals up to a quarter of an inch on a side. Some pyrite crystals are scattered at random through the dyke, but most of them are along narrow cracks which may contain a little calcite or quartz. The cracks are most numerous along the fine-grained margins of the dyke. They appear to be contraction cracks formed when the dyke rock cooled. Pyrite is disseminated in the slate near the dyke.

The schist of Grand Verdun Island (Green Island) has been affected by high-temperature mineralizing solutions. This conclusion is based on the presence of numerous veinlets of specular hematite associated with quartz and calcite. The observed sulphide is all of the pyrite type as represented by assays (3) and (4). It is possible that some calcite-chalcopyrite deposits along shear zones on Northeast Island were formed by the same solutions. Pyrite is widespread at the south end of Grand Verdun Island, apparently related to a diabase dyke and a strong east-west shear zone. Assay (4) is of a badly sheared and carbonatized dyke which contains scattered grains of pyrite with a trace of chalcopyrite. Assay (3) is of a schist layer which contains many irregular grains and cubes of pyrite with a little chalcopyrite. In general, the rock is similar to other members of the schist, (p. 24) except that it contains quartz augen and a rather large amount of chlorite and titanite.

Table III*

ASSAYS OF PYRITE-BEARING ROCKS

	(1)	(2)	(3)	(4)
Gold	Nil	Nil	Nil	Nil
Copper	Nil	Not determined	Not determined	Traces

(1) Silicified zone in Goose Cove schist with fine pyrite, near Goose Cove.
(2) Altered dyke with calcite-pyrite veins, Spring Arm.
(3) Pyritized schist, Grand Verdun Island (Green Island).
(4) Mineralized dyke, Grand Verdun Island (Green Island).

*Assays by J. F. Newman.

Lead and Zinc

Small amounts of lead and zinc are present in the Hare Bay area, but there is little indication that there are workable deposits. The writer did not see any lead occurrences, but several of the local fishermen displayed pieces of galena which were reported to have come from the northeastern part of the map area. Unfortunately, no one could be engaged to take the writer to any of the deposits. As far as can be told from verbal descriptions, the galena is present in small amounts. It is possible that it was secured from glacial drift.

There are two local modes of occurrence of zinc. It is a minor constituent of the Goose Cove copper ores and is present in minute amounts in some calcite veins near the west end of Shoal Arm (South Arm), Hare Bay. Zinc is in the mineral sphalerite which occurs in a number of closely spaced calcite veins, the strike of which is north 60 degrees east. The individual veins are an inch or two thick except locally where bunches of calcite up to eight inches wide were observed.

The limestone country rock is somewhat silicified near the veins and there are small vugs which contain minute quartz crystals. Sphalerite is scarce, occurring as small resin-coloured crystals along the sides of the veins and in the limestone near them. The most significant feature of the occurrence is the presence of a small amount of pink apophyllite molded over quartz crystals. This indicates that the veins are of hydrothermal origin and belong to the epithermal class. The mineral apophyllite is diagnostic of this class of deposits. Its best-known occurrence is in the zeolite association present in cavities and veins of basalts and diabases. The mineral occurs also at the mercury mines of New Almaden, California; and a pink variety is reported from the silver veins at Andreasberg, Germany and Guanajuato, Mexico (7, pp. 642-643).

Quartz Veins

Though devoid of valuable minerals, numerous large quartz veins in the Maiden Point sandstone should be mentioned. They are large gash veins which generally strike parallel to the regional structure. Many of them exceed five feet in width, but none continues far along the strike (Fig. 15). There is no obvious system to their distribution although they appear to be most numerous near faults.

The veins were formed after the regional deformation but before the intrusion of the diabase dykes (Fig. 16). They appear to be of hydrothermal origin. Milky quartz is the principal mineral although some calcite is nearly always present. The calcite is most commonly in blades which cut the quartz, but is occasionally present along the center of the veins where it is molded over quartz crystals. Part of the quartz is green because of minute inclusions of chlorite. Occasionally, chlorite is found in calcite and in irregular cracks through the quartz.

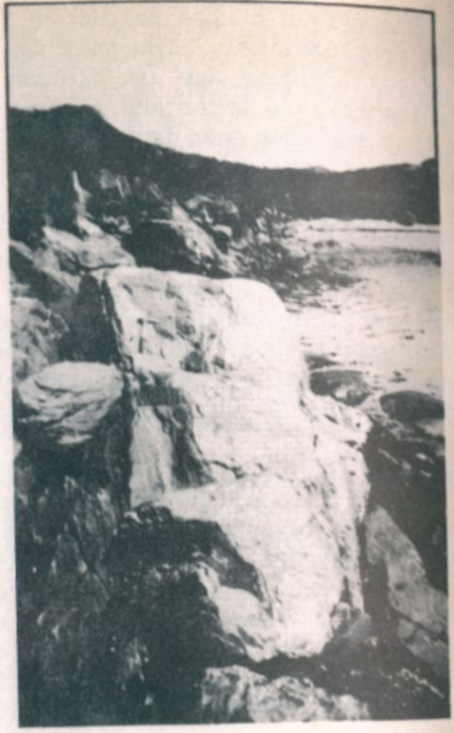


Fig. 15. Large quartz vein on the north shore of Four Harbours. Hammer in left center gives the scale.

Limestone

There is plenty of limestone in the Hare Bay area for use as building stone, crushed stone, and agricultural or chemical lime. The stone in various places is particularly well suited for these purposes. The Hare Island limestone is hackly and weathers to a rubble which is like artifically crushed stone. The International Grenfell Association has secured gravel for the roads at St. Anthony from a raised beach of this rubble in Little Arm, Hare Bay. There is a large quantity of such material ready for use whenever there is demand for it.

Suitable building stone is present at a number of places within the Southern Arm limestone. According to local report, there is a place near the shore of Southern Arm where the rock is broken into rectangular blocks, ideal for building. This is

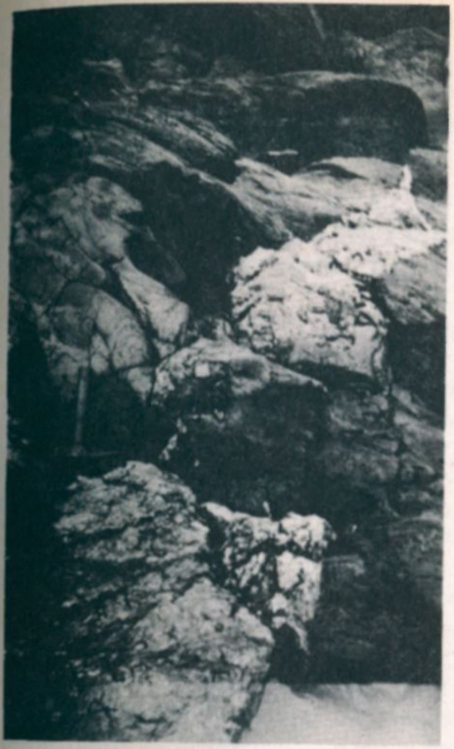


Fig. 16. Diabase dyke crossing early-formed quartz vein in Buse Point Bay. The quartz vein is barren of metallic minerals except near the dyke where there has been some impregnation of pyrite.

probably due to the presence of two joint systems at right angles to each other which cut through a well-bedded member of the formation.

The agricultural use of lime is a promising but as yet untried practice in northern Newfoundland. The ill-drained soils of the region are doubtless too acid for the most advantageous growth of farm products. The acidity can be overcome by the use of crushed limestone or burned lime. It is likely that a material increase in production of vegetables and of fodder for domesticated animals could be accomplished by using the local limestone as a fertilizer.

Three chemical analyses* have been made in order to test the suitability of the local stone for agricultural purposes. The International Grenfell Association secured an analysis of a reddish limestone from the Springs, Hare Bay, It showed:

Silica	0.91%
Calcium carbonate	94.11
Magnesium carbonate	4.70
Potash	0.24
Total	99.96

Partial analyses of (1) hackly limestone from Hare Island and (2) naturally crushed limestone from Little Arm are as follows:

	(1)	(2)
Insoluble residue	0.90%	Not determined
Lime	51.80	53.40
Magnesia	Minute trace	Minute trace
Loss on ignition	39.67	Not determined

These indicate that the stone is well over 90 percent calcium carbonate.

All three analyses are of the Hare Island limestone which, like its correlative of the west coast (Table Head series), is a rather pure limestone. It is likely that magnesian limestones and dolomites are present in the Southern Arm limestone because of its appearance and also because its correlative of the west coast (St. George series) is typically dolomitic (17).

Slate

Well-developed flow cleavage in the Goose Tickle slate suggests that certain parts of the formation might be used as roofing slate. There is, however, almost no local demand for it, and it is unlikely that the product would be of sufficiently high grade to compete in foreign markets. There are places, such as along the shore of Shoal Arm (South Arm), where large flat slabs can be split off. Some of these might be used for roofing material. The rock is considerably fractured, however, and there are thin silty and limy beds which make lines of weakness in the slate.

Coal in Pistolet Bay

Small pieces of bituminous coal are numerous on the tidal flat at the southwest corner of Pistolet Bay. This has led to a widely accepted belief that there are coal deposits in the vicinity. Several mining claims were staked in August, 1936. There is no coal deposit on these claims or anywhere else in the region. The underlying rock is closely folded Goose Tickle slate of Ordovician age which does not carry coal. The coal fragments must have come from some vessel which was wrecked in Pistolet Bay or floated there from a wreck in the Strait of Belle Isle. The oldest inhabitants have no recollection of such a wreck and there is no local tradition about it. This is not surprising when it is remembered that this is part of "the French shore" and until comparatively recent years was occupied by French fishermen.

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*Analyses by J. F. Newman.

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